Los Angeles County
Metropolitan Transportation Authority

Climate Action and Adaptation Plan

JUNE 2012

Metro®

Table of Contents

List of Figures

List of Tables

List of Abbreviations

APTA: American Public Transportation Association

BCF: billion cubic feet

BRT: bus rapid transit

CARB: California Air Resources Board

CCSM: Community Climate System Model

CH_4: methane

CNG: compressed natural gas

CNRM: Centre National de Recherches Météorologiques

CO_2: carbon dioxide

DJF: December, January, February

ECMP: Energy Conservation Management Plan

GFDL: Geophysical Fluid Dynamics Laboratory

GHE: gasoline hybrid electric

GHG: greenhouse gases

GWP: global warming potential

JJA: June, July, August

LACMTA: Los Angeles County Metropolitan Transportation Authority

LED: light emitting diode

LRTP: Long Range Transportation Plan

MAM: March, April, May

$MMTCO_2e$: million metric tons of carbon dioxide equivalents

MSIP: Metro Sustainability Implementation Plan

MT: metric tons

$MTCO_2e$: metric tons of carbon dioxide equivalents

N_2O: nitrous oxide

NCAR: National Center for Atmospheric Research

PCM: Parallel Climate Model

PMT: passenger miles traveled

PV: photovoltaic

ROW: right of way

SF_6: sulfur hexafluoride

SON: September, October, November

TIGGER: Transit Investments for Greenhouse Gas and Energy Reduction

TOD: transit oriented development

WESS: wayside energy storage substation

Executive Summary

Introduction

Metro is the principal provider of public transportation in Los Angeles County and also the County's transportation planner and coordinator, designer, builder, and operator. As a public transportation agency, Metro has a specific role in addressing climate. Well-planned and well-used public transportation reduces climate changing greenhouse gas (GHG) emissions by creating alternatives to driving and fostering communities that enable more walking and bicycling. Public transportation systems also consume fuel and electricity and thereby produce GHG emissions; however, most transit agencies, including Metro, prevent more emissions than they create. In spite of efforts to reduce GHG emissions, some degree of climate change is likely to occur over the next century, with impacts including rising sea levels, rising temperatures, and more extreme weather patterns. Metro is also responsible for protecting critical services and assets in the transportation system from these impacts. This Climate Action and Adaptation Plan ("the Plan") establishes the framework for Metro to both reduce GHG emissions and prepare for the impacts of climate change. Emissions from 2010 are used as a baseline in the Plan because at the time the Plan was prepared, 2010 emissions data was the most up to date and complete data set available.

Reducing Greenhouse Gas Emissions

This Plan establishes a framework to identify the areas of greatest opportunity for Metro to reduce GHG emissions and evaluates opportunities based on their costs and the volumes of emissions they reduce. Metro's influence on GHG emissions extends to all of the County's transportation systems. As a first step, the Plan focuses on prioritizing the most promising opportunities to reduce emissions from Metro's internal operations by the year 2020. The analysis on which the Plan is based consisted of four steps:

1. Inventory 2010 operational GHG emissions and forecast 2020 emissions.
2. Survey GHG reduction strategies that have been deployed or are under development at Metro or other transit agencies.
3. Quantify the costs and GHG reduction potential of the 11 strategies that appear to be most likely to offer cost effective reductions in GHG emissions by 2020.
4. Quantify the costs and GHG reduction potential of four potential packages of strategies.

Inventory and forecast

In 2010, Metro emitted 476,000 metric tons of carbon dioxide equivalents ($MTCO_2e$) from its operations, or roughly 1.04 $MTCO_2e$ per thousand passenger boardings. For comparison, these emissions account for roughly 1.9 percent of the GHG emissions from all road- and rail-based passenger transportation in Los Angeles County. Metro's transit service accounts for almost 90 percent of the agency's emissions; facilities and non-transit vehicles account for the remainder. Though Metro emits a substantial amount of GHG emissions, the agency displaces more emissions than it produces by offering alternatives to driving and fostering sustainable communities.

From 2010 to 2020, Metro's yearly GHG emissions will increase by seven percent, largely due to expanded bus service and new rail lines. However, annual passenger boardings are expected to increase at an even faster rate, growing by 12 percent, so emissions per passenger boarding will fall by 4.4 percent. An even greater portion of these emissions—95 percent—will come from transit as service expands and actions already underway at both Metro and the State increase the energy efficiency of the agency's buildings.

Strategy analysis

Metro surveyed both internal studies and studies conducted by other transit agencies for potential strategies to reduce emissions, and ranked each in terms of their potential for cost effective reductions in GHG emissions by 2020. Metro then analyzed the 11 highest-scoring measures that are focused on reducing operational emissions. Table ES1 summarizes the cumulative GHG reductions and cost-effectiveness of each measure.

Table ES1: Cumulative Reductions and Cost Effectiveness of Strategies to Reduce GHG Emissions

Strategy	Cumulative GHG Reductions (MT CO2e), 2012–2020	GHG Reduction Cost Effectiveness ($/MT)*
Use Biomethane in CNG Buses (well-to-wheels impacts)	528,555**	$174-379
On-board Railcar Braking Energy Storage	96,411	$180
Gasoline-Electric Hybrid Buses (tank-to-wheels impacts)	76,826	$4,922
Building Indoor Lighting Upgrades: LEDs	71,621	-$78
Building Indoor Lighting Upgrades: Efficient Metal Halides	46,226	-$117
Wayside Energy Storage Substation (WESS)	17,289	$2,774
Retrofit Lighting in Red Line Tunnel	5,783	-$73
Expand Use of Renewable Energy	4,467	$2,303
Municipal Recycled Water For Bus Washing	941	-$570
Extension of Bus Wash On-Site Reclamation	544	-$2,378
Low Water Sanitary Fixtures	424	-$907
Mobile Air Conditioning Replacement	353	$3,103

** Negative numbers indicate a net savings.*

*** Using biomethane in CNG buses reduces well-to-wheels emissions due to fuel production that are not accounted for in Metro's GHG inventory.*

NB: All costs represented are costs to Metro only, and do not include cost impacts to transportation users or other public agencies.

As transit vehicles and systems account for the majority of Metro's GHG emissions, many of the strategies in Table ES1 that deal with buses and rail systems produce correspondingly large reductions. However, these strategies also often involve large net costs for Metro, and are therefore generally not as cost effective as building energy and water strategies, which tend to save Metro money.

Metro is most likely to implement a package of strategies that reduce GHG emissions. To demonstrate the total impact that multiple strategies could have together, four potential packages of strategies were analyzed, as follows:

1. **Short-Term Cost Saving Strategies—**These are strategies that will provide net savings to Metro by 2020 and are ready for implementation in the near term using readily available methods. They include all strategies related to water and lighting.
2. **Short-Term and Mid-Term Strategies—**All strategies that are ready for implementation in the near term using available methods, as well as additional strategies that are appropriate for wider implementation pending the results of demonstration projects. They include all short-term strategies as well strategies related to rail and renewable energy.
3. **All Strategies with Tank-to-Wheels Benefits—**All strategies that would reduce GHG emissions that are currently counted as part of Metro's GHG inventory. This package excludes the use of biomethane in CNG buses.
4. **All Strategies with Well-to-Wheels Benefits—**All strategies that would reduce GHG emissions regardless of whether or not they are included in Metro's GHG inventory. This package includes the use of biomethane in CNG buses, but excludes gasoline-electric hybrid buses, which are not compatible with the biomethane strategy.

Table ES2 summarizes the GHG reductions potential and net cost to Metro for each package of strategies, between 2012 and 2020.

Table ES2: GHG Reductions and Cost Effectiveness of Packages of GHG Reduction Strategies

Package	Cumulative GHG Reductions (MT CO2e) 2012-2020	Net Cost (2012-2020)*	Reduction in Forecast GHG emissions in 2020	Reduction in GHG emissions per boarding from 2010 to 2020
1. Short-Term Cost Saving Strategies	66,616	-$8,121,116	0.6%	5.0%
2. Short-Term and Mid-Term Strategies	167,494	$67,443,140	4.3%	8.6%
3. All Strategies with Tank-to-Wheels Benefits	244,673	$446,719,774	7.4%	11.5%
4. All Strategies with Well-to-Wheels Benefits	696,402	$206,873,542	28.9%	32.1%

** Negative numbers indicate a net savings.*

NB: All costs represented are costs to Metro only, and do not include cost impacts to transportation users or other public agencies.

Recommendations

Based on this analysis, the Plan concludes that Metro could meet a goal of reducing internal GHG emissions by 0.6% in the year 2020 using cost effective strategies. This is equivalent to reducing the agency's GHG emissions per boarding by 5.0% from 2010 to 2020. As Table ES2 shows, Metro can meet this goal while saving money. Metro has multiple pathways to meeting this goal, including:

- Implement Short-Term Cost Saving Strategy Package – All lighting strategies in this package are underway or scheduled to begin shortly. To implement the remainder of this package, Metro would need to expand its current water saving strategies and ensure their proper operation.
- Partially Implement Short-Term and Mid-Term Strategy Package – It is likely that Metro will have two grant-funded WESS projects operational by 2020, and the agency is already planning to construct several new solar photovoltaic projects on facilities. Metro could attain the proposed goal by implementing the WESS projects on schedule, installing 0.5 MW of additional solar photovoltaic capacity, retrofitting the Red Line tunnel lighting, and completing facility lighting upgrades by 2020.

Adaptation

The adaptation component of the plan is a high-level screening analysis, designed to identify some of the most important Metro services and assets that are likely to be affected by climate impacts. The Plan outlines options for ensuring that these services and assets continue to function as the climate changes. This analysis consisted of four steps:

1. Identify the critical assets and services within the Metro system.
2. Examine local historical climate data and projections for future climate conditions.
3. Qualitatively assess the vulnerability of critical services and assets.
4. Identify potential adaptation strategies that can address these vulnerabilities.

Critical services and assets

This Plan used a simple and qualitative definition of criticality: critical services and assets are those that are essential to transporting Metro's customers. A critical service or asset would be extremely difficult or costly to replace or to substitute. Critical assets and services include:

- bus and rail fleets
- right-of-way on bus rapid transit (BRT) lines
- heavy rail tracks, stations, and energy infrastructure
- light rail tracks, stations, and energy infrastructure
- rail rehabilitation activities

In addition, the Plan identifies critical facilities. Transit facilities were ranked according to their ridership, connectivity to other parts of the transit network, and whether they are the site of current or planned joint development projects. To identify other types of facilities as critical, including maintenance facilities and administrative buildings, the Plan relied on expert opinions from Metro officials. Critical facilities include several key rail stations, the main bus maintenance facility, two important rail maintenance locations, and Metro's administrative headquarters. Transit projects that are planned for construction using Measure R funds are also considered critical due to the sizeable investments required to complete these projects.

Future climate conditions

Metro drew on historical data on temperature, rainfall and sea level rise, as well as climate models, to examine future climate conditions in Los Angeles County through the end of the century. Major findings include the following:

- Temperatures are projected to continue to rise, possibly in excess of 10°F, and the frequency of extremely hot days is expected to increase.
- There is some evidence of a recent increase in the frequency of events of heavy precipitation, but it is unclear if such a trend might continue into the future. Regardless, the region will continue to experience events of heavy rainfall in the future.
- Sea levels are expected to rise one foot by the mid-21st century and between 20 inches and five feet by the end of the century. However, the risk of impacts from sea level rise is low due to the inland location of most transit assets.

Vulnerabilities and adaptation options

Metro qualitatively assessed the vulnerability of critical services and assets to changing climate conditions in the region based on their exposure to impacts, their sensitivity to extreme heat and heavy rain, and their capacity to adapt to climate impacts through replacement, relocation, or retrofitting. Based on this analysis, the agency identified potential options for adapting each of the critical services and assets. Table ES3 summarizes the vulnerability of critical services and assets and outlines potential adaptation options.

Table ES3: Summary of Vulnerability Analysis and Potential Adaptation Options

Service/Asset	Climate Impact	Potential Adaptation Option
Rail Operations	Equipment malfunction (electrical systems; air conditioning systems) during periods of extreme heat	• Pre-emptive maintenance or inspection; weather/climate-related monitoring
	Railway buckling during periods of extreme heat	• More heat-resistant materials or designs, if available • Increased shading of railways
	Flooding of underground stations and tracks during heavy rainfall events	• Improved stormwater management systems • Infrastructure upgrades in stations (ventilation grates, entrances, seals) • Increased pumping capacity
	Flooding of at-grade railways and (Bus Rapid Transit right-of-ways[1]) during heavy rainfall events	• Upgraded stormwater management systems

[1] Although BRTs are part of Bus Operations, the right-of-ways are functionally more similar to a railway.

Bus Operations	Fleet breakdowns and maintenance during periods of extreme heat	• Pre-emptive maintenance or inspection; weather/climate-related monitoring
New Construction/ Measure R Projects	Exposing new infrastructure to episodes of extreme heat and heavy rainfall events	• Integration of climate considerations in siting and alternatives decisions
	Labor interruptions or delays during periods of extreme heat	• Modification of construction schedules, especially during summer months

Next steps

Next steps to evaluate and expand upon the GHG reduction strategies in the Plan include:

- Establish an interdepartmental working group to monitor the implementation of strategies and progress towards reduction goals. This group could also schedule regular check-ins on emerging technologies.
- Update the Plan with analyses of strategies that reduce emissions from regional transportation, such as strategies that promote transit use, carpooling, and bicycling.
- Update the Plan with new information every 5 years, or more often if significant changes in technology, policy, or legal requirements warrant more frequent updates.
- In future plan updates, include a section on local, state, and federal regulations that directly affect Metro's GHG emissions, such as new vehicle technology regulations.
- Use the annual Sustainability Report to document strategies selected for implementation and monitor progress.

Next steps as Metro moves toward evaluating specific options for adapting to climate change could include:

- Investigate climate vulnerabilities at a higher level of specificity.
- Explore the monetary and social costs of climate impacts and adaptation options.
- Develop a communications strategy for the adaptation component of the Plan and subsequent adaptation activities.
- Explore implementation of climate adaptation principles at the operations level through the FTA-funded Climate Adaptation Pilot Program.

1. Introduction to the Plan

As a public transportation agency, Metro has a specific role in addressing climate change at both global and local scales. Public transportation, when well planned and well used, reduces vehicle travel and congestion on roadways, and helps to create communities that enable more walking and bicycling. These impacts in turn reduce emissions of greenhouse gases (GHGs), which contribute to climate change. Even though public transportation agencies produce GHG emissions from their vehicles and facilities, most of them (Metro included) prevent more emissions than they create. Reducing GHG emissions means slowing the worldwide impacts of climate change, which include rising sea levels, rising temperatures, and more extreme weather patterns.

Metro and Los Angeles County will inevitably be affected by a changing climate. Extreme temperatures and higher risk of flooding bring operational and maintenance challenges to Metro's buses and trains. Some assets may have shorter lifespans than originally envisioned, or require structural reinforcements to protect them from long term damage. Preparing for these impacts now can mitigate damage to Metro's transportation systems in the future.

The American Public Transportation Association (APTA) has articulated the relationship of transit agencies to climate change in its *Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit* ('the APTA Protocol'). APTA encourages transit agencies to take stock of the emissions that they produce as well as the emissions that they prevent. APTA also maintains a Sustainability Commitment, to which Metro is a signatory. Pledging to reduce GHG emissions is part of some signatories' commitments. Finally, APTA has released *Guidelines for Climate Action Planning*, in order to encourage transit agencies to work proactively to reduce GHG emissions and prepare for the effects of climate change.

This plan is presented in support of APTA's guidance, and in support of Metro's role as a steward of the environment and of Los Angeles County's transportation assets. Sustainability, including reducing GHG emissions, is one of Metro's core business goals. Fiscal responsibility is another one. Determining how best to protect and preserve Metro's assets from the impacts of climate change is a fiscally responsible action. Public transportation agencies can and must take action on climate change. This plan establishes the framework for the agency to take steps to both reduce GHG emissions and prepare for the impacts of climate change.

1.1. Plan Objectives

Metro has compiled this Climate Action and Adaptation Plan ("the Plan") to serve dual purposes:

1. **Create a framework to evaluate and prioritize areas of opportunity for Metro to reduce GHG emissions from operations.**

   Metro has many opportunities to reduce GHG emissions from its buses, trains, and facilities. There are also opportunities to reduce emissions generated by travel in private vehicles in Los Angeles County. Many of these are described in Metro's *Greenhouse Gas Emissions Cost Effectiveness Study*, which estimated the cost and emissions impacts of 17 current and potential future strategies to reduce emissions. All of the strategies involve some upfront cost, but some of them save money for Metro over time. All of the strategies have implications beyond GHG emissions. Some would require changes to the way that Metro operates and maintains its assets. Others would change the experience of Metro's riders.

This Plan establishes a framework to identify the areas of greatest opportunity for Metro to reduce GHG emissions, based on estimates of cost and emissions impacts. Strategies examined in this plan will in many cases require further analysis before they can be implemented. The Plan contains key steps to move each strategy toward implementation. As new opportunities to reduce GHG emissions inevitably arise and new information about strategies becomes available, this Plan can be updated to refine priorities and action steps for the agency to reduce GHG emissions.

Metro is the principal provider of public transportation in Los Angeles County and also the County's transportation planner and coordinator, designer, builder, and operator. As such Metro's influence on GHG emissions extends to all of the County's transportation systems. As a first step, the Plan focuses on identifying and prioritizing actions that would affect just Metro's internal operations. Strategies examined in detail are those that would reduce emissions created by Metro from its buses, trains, and facilities. Subsequent versions of this Plan should incorporate actions to reduce travel in private vehicles into the framework.

2. **Present an approach for responding to the likely impacts of climate change on Metro's system.**

   Adaptation options are based upon the ways in which climate conditions are anticipated to affect Metro's infrastructure and operations. In an effort to identify options for Metro, the Plan presents a combined analysis of Metro's major services and assets, the ways in which these assets and services are sensitive to climate, and information about expected future climate conditions.

   The adaptation options presented in the Plan, as well as the analysis that underlies the discussion of Metro's climate vulnerability, are based on a high-level perspective of Metro's infrastructure and operations. This analysis demonstrates a strong link between climate impacts and the ability of Metro to reliably provide service to its customers. In this context, the presentation of adaptations is intended to motivate and guide future research and consideration of potential climate impacts and adaptation strategies, and to provide some of the technical information that can support such activities.

1.2. How to Use this Plan

Mitigation

The strategies included in this Plan are Metro's most promising opportunities to reduce GHG emissions from operations by the year 2020. A horizon year of 2020 is used in order to focus on short-term and medium-term actions to reduce emissions. A baseline year of 2010 is used because it was the most recent GHG emissions data available during development of the Plan. 2020 is also the horizon year for California's GHG reduction goal. Metro's actions can contribute to the achievement of this goal.

Not all of the strategies in the Plan can or should be implemented. The Plan is not intended to identify the best investment for a given asset type. Instead the Plan identifies asset and investment types that should be investigated in further detail, given their potential to reduce emissions. Metro has conducted (and continues to conduct) a number of more detailed studies of opportunities to improve the sustainability of its operations through water conservation, energy conservation, and management of other resources. Some options analyzed in previous documents are included as strategies in the Plan. Those detailed studies are the appropriate medium for analyzing technical options in greater detail.

The information contained in this Plan should be used to support a balanced decision-making process to select strategies that improve the overall sustainability of the agency. Impacts on GHG emissions are only one of a number of factors that influence Metro's investment decisions. All of the strategies evaluated in this report have benefits in addition to GHG reduction, such as reducing transit operating costs, increasing transit ridership, improving mobility, reducing water use, and providing employee benefits. Some strategies involve significant costs. ***Decisions to support any individual strategy should be made based on a composite assessment of all these potential benefits and costs, rather than GHG impacts alone.***

Adaptation

The Plan's approach to considering climate change adaptation is also not intended to provide definitive recommendations. Rather, the Plan provides methodologies and analyses as technical inputs to future discussions of adaptation strategies.

It is clear that any decisions to implement adaptation measures will require significantly more specificity and technical detail than are provided in the Plan. Moreover, the choice to pursue any particular adaptation option will involve broad considerations of a variety of Metro management goals as well as more detailed information about costs and benefits.

In short, the Plan is intended as a first step to inform and facilitate Metro's longer-term commitment to bolstering its resilience to climate variability and climate change.

As a next step, Metro's FTA-funded Climate Adaptation Pilot Program uses principles outlined in the Plan and explores operational climate resiliency from the ground up as a counterpart to the Plan. Metro is taking a two part approach to integrating climate adaptation principles in the agency's processes: top-down planning in this Plan and bottom-up planning from Metro operations.

1.3. The Climate Action and Adaptation Plan in Context

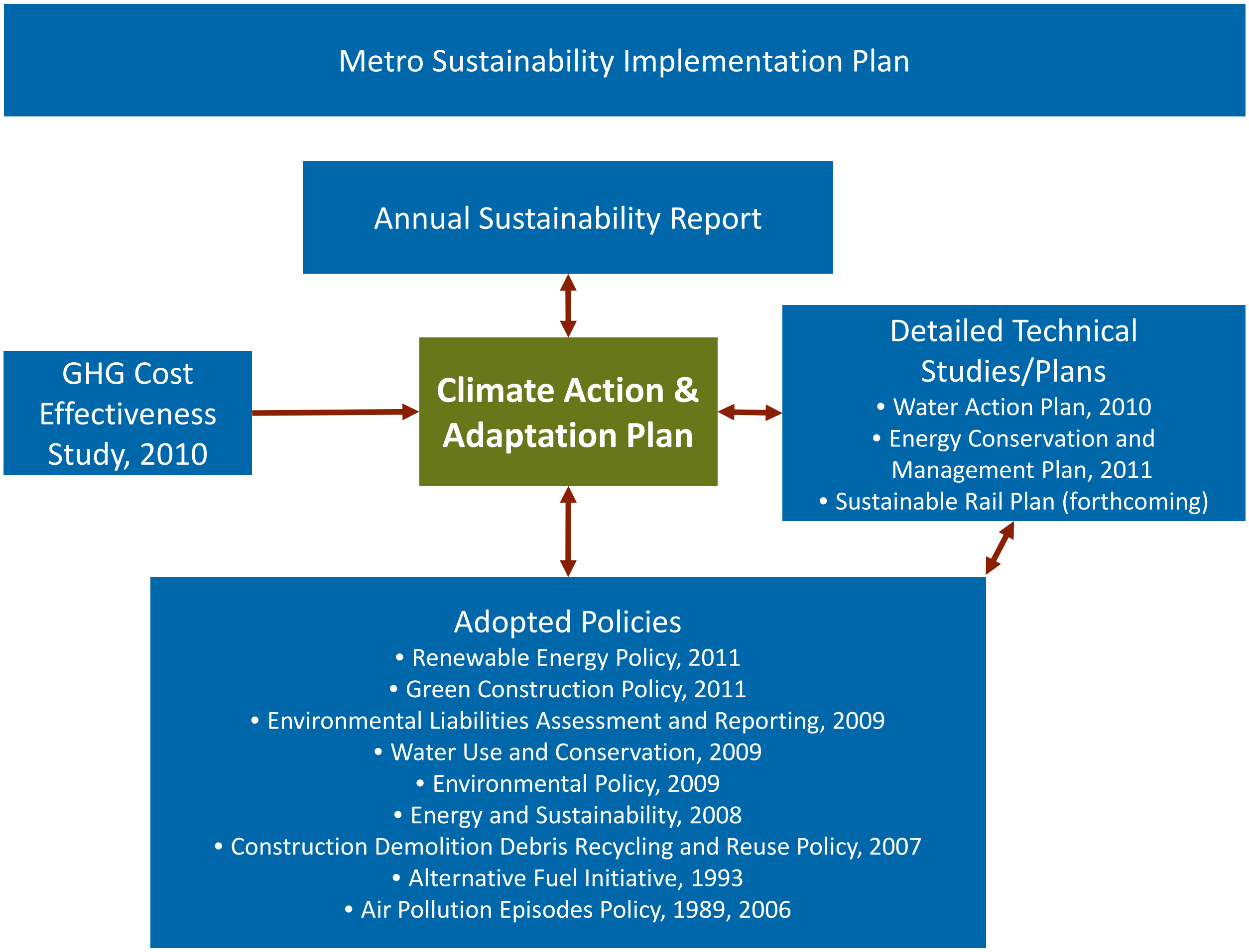
This Plan is part of Metro's long-term Sustainability Program. The Sustainability Program was initiated with the 2008 *Metro Sustainability Implementation Plan (MSIP),* intended to demonstrate Metro's commitment to sustainability through fiscal responsibility, social equity, and environmental stewardship. Metro and Countywide GHG Emissions Management was one of four sustainability projects identified in the MSIP.

Since 2008, Metro has conducted a number of studies and planning efforts under the Sustainability Program. The agency has also issued several policies since 2008 that support the agency's sustainability agenda. A few of the agency's sustainability polices predate the MSIP.

Development and implementation of the Plan will be consistent with the "Plan-Do-Check-Act" model that was established through Metro's Environmental Management System (EMS). An EMS is a set of operational procedures that will ensure compliance with environmental regulations and facilitate environmental stewardship. Metro committed to the establishment and use of an EMS in the 2009 *Environmental Policy*. The EMS has been piloted in two Metro divisions and will soon be rolled out agency-wide. Through the EMS, Metro has been identifying environmental issues of significant concern, proactively addressing those issues, implementing specific solutions to issues as they are developed, and engaging Metro management to ensure continuous improvement. Thus, the EMS provides the structure for managing all environmental issues for Metro; the Climate Action and Adaptation Plan fits within this structure and provides more specific approaches to address climate change mitigation and adaptation.

The graphic below demonstrates the relationship of the Plan to the rest of Metro's Sustainability Program. The MSIP outlines several key goals for the Sustainability Program. Metro's annual Sustainability Report tracks the agency's progress on a number of sustainability indicators, including GHG emissions, energy used, and waste production. The Sustainability Report also documents successful actions and potential future actions.

Figure 1: Relationship of the Climate Action and Adaptation Plan to Other Sustainability Initiatives



Metro's 2010 *GHG Emissions Cost Effectiveness Study* was the agency's first attempt to estimate the impact that it has and can have to reduce GHG emissions through various strategies related to vehicles, facilities, and transportation demand management. The impact of current programs was analyzed on an average annual basis. The impact of potential future strategies was also analyzed on an average annual basis.

This Plan incorporates many of the strategies included in the *Cost Effectiveness Study*. The Plan asks specifically how much Metro can reduce emissions from operations by the year 2020, through combinations of various strategies. The Plan concludes that Metro could meet a goal of reducing internal GHG emissions per passenger trip by 5.0% from 2010 to 2020, and demonstrates how that goal can be achieved through improvements to various asset types.

The Plan complements Metro's more detailed technical studies and plans as well as Metro's adopted sustainability policies. A series of technical studies provides more depth on specific types of strategies, including water saving strategies and energy management strategies. A forthcoming Sustainable Rail Plan will provide more technical guidance about the best ways to save energy in Metro's rail system. Some strategies from previous studies are represented in this Plan, in order to compare their GHG impacts to strategies applicable to other asset types.

The Plan also highlights needs for additional detailed technical studies. These technical studies are the appropriate media for considering the full range of costs and co-benefits of individual strategies, so that informed implementation decisions can be made.

Metro's sustainability policies codify decisions about the use of renewable energy, green construction methods, water conservation, and other environmental efforts. Some of these policies affect Metro's GHG emissions; their impacts were considered in this Plan. Likewise the Plan may highlight opportunities to establish new sustainability policies in the future, to codify any implementation actions forthcoming from the Plan.

1.4. Organization of the Plan

The remainder of this plan is divided into two main sections. The first section addresses the need to mitigate climate change by reducing GHG emissions. It provides an accounting of Metro's current and forecast emissions, as well as a discussion of actions that Metro can take to further reduce emissions from private vehicles. The bulk of this section presents a framework for reducing emissions from Metro's internal operations. Eleven strategies are described and analyzed. Using the results of the analysis, the Plan demonstrates pathways by which Metro can achieve a GHG reduction goal. The section concludes with suggested implementation steps for each strategy.

The second section identifies some of the most important Metro services and assets that are likely to be affected by climate impacts. The section describes the methodology for identifying the important, or "critical," services and assets. It also includes a discussion of recently observed climate variability and climate change, anticipated future climate conditions, and the implications of these future conditions for Metro's services and assets. The concept of climate vulnerability is introduced and applied to Metro's services or assets to yield a "short-list" of potential risks. Finally, several adaptation strategies are presented that could address these vulnerabilities.

A final chapter provides next steps for both the mitigation and the adaptation components of the Plan. A series of technical appendices provides more detail on the analysis methodologies used in the Plan.

2. Reducing Greenhouse Gas Emissions

This section discusses Metro's GHG emissions and opportunities for reducing emissions. An inventory of Metro's current emissions (as of 2010) and forecast of future emissions in 2020 are provided. These provide an important context for considering strategies to reduce emissions. Metro's current impact on regional transportation emissions is briefly explored. Metro's options to reduce emissions from its internal emissions are then described and analyzed.

2.1. Greenhouse Gas Inventory and Forecast

Metro's inventory and forecast includes two categories of emissions:

- Emissions produced (internal emissions)
- Emissions displaced (external emissions)

Emissions produced are generated by vehicles and buildings owned by Metro. These include emissions from fuel combustion occurring in Metro vehicles, purchased transport, facilities, water use, and on-site use of high global warming potential (GWP) gases.

Metro also keeps GHGs out of the atmosphere by allowing transit riders to leave their cars at home and by supporting other forms of low emission travel options. As discussed in guidance from APTA, mode shift is used to quantify how Metro's service displaces GHG emissions. Metro reduces the amount of VMT on Los Angeles County's roads by getting people out of their cars and onto Metro buses, trains, and vanpools.

Metro's inventory and forecast use standard GHG inventory methodologies as provided in the APTA Protocol and by agencies such as The Climate Registry and the World Resources Institute. Emission factors are drawn from the California Climate Action Registry (2009). Since the inventory and forecast are only used internally, they are structured to provide the best information for the Plan, rather than for strict adherence to a single protocol.

Metro's inventory and forecast incorporate five GHGs:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Sulfur hexafluoride (SF_6)
- Refrigerants

Metro's GHG Emissions: 2010

In 2010, Metro emitted 476,488 metric tons of carbon dioxide equivalents ($MTCO_2e$) from all its operations, which include both fleet transport as well as facility energy use.[2] With over 460

[2] Metro's 2010 GHG emissions inventory has been revised since the release of the 2011 Metro Sustainability Report. This revised figure is reflected in the 2012 Metro Sustainability Report.

million boardings in 2010, Metro's GHG emissions were 1.04 $MTCO_2e$ per thousand boardings. As shown in Figure 2, CNG bus transport accounts for the majority of emissions from Metro operations in 2010 at 63% of all internal emissions. Metro's rail system accounts for nearly one fifth of the agency's GHG emissions. In total, Metro's transit service, including buses, rail, and vanpools, accounts for 89% of GHG emissions.

Although there was diesel and gasoline usage in 2010, the emissions associated with the use of these fuels are negligible compared to the other sources. Water use, SF6, and refrigerants are also negligible compared to the emissions from other sources.

Table 1 provides the data associated with Figure 2.

Figure 2: Metro Internal Emissions by Source in 2010 (%)

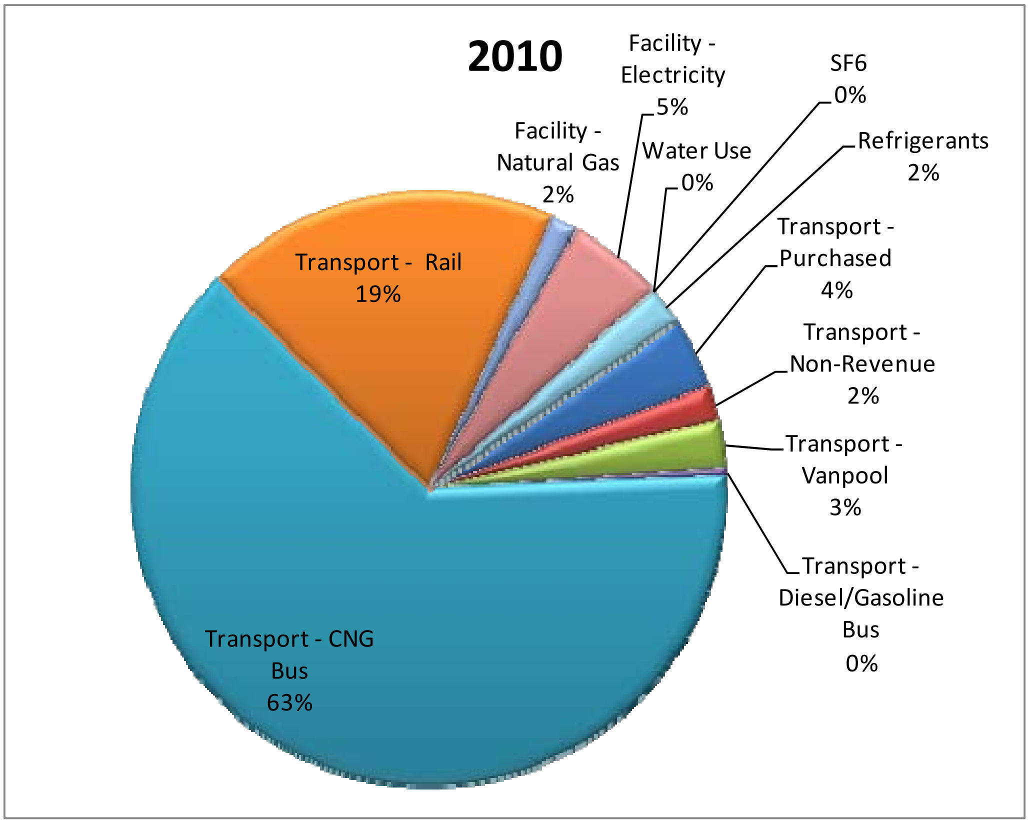


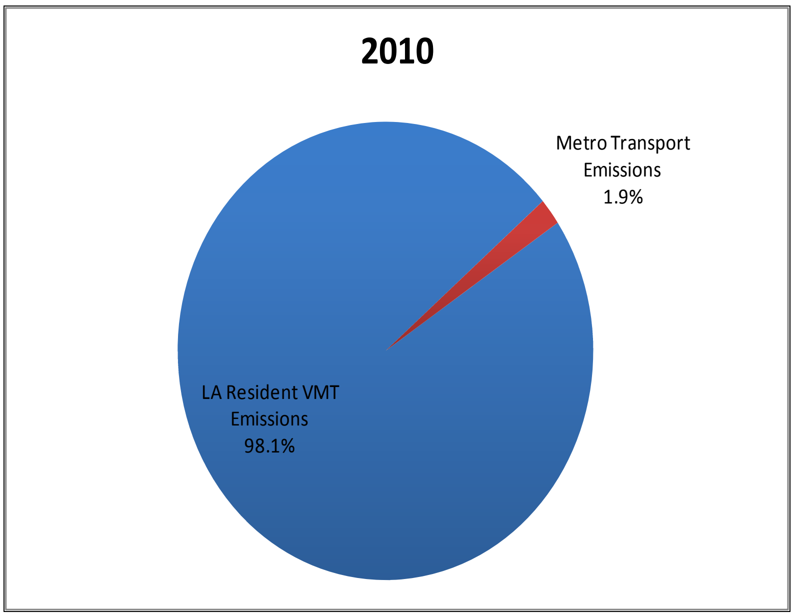
Table 1: Metro Internal Emissions by Source in 2010

Sector	Emissions ($MTCO_2e$)	Percent of Total Emissions
Transport—Purchased	18,965	4%
Transport—Non-Revenue	8,924	2%
Transport—Vanpool	12,301	3%
Transport—Diesel/Gasoline Bus	1,842	0%
Transport—CNG Bus	301,373	63%

Transport—Rail	92,229	19%
Facility—Natural Gas	6,771	1%
Facility—Electricity	25,051	5%
Water Use	294	0%
SF6	16	0%
Refrigerants	8,722	2%
Total:	476,488	100%

Figure 3 compares Metro's emissions from transit service to emissions from travel in private vehicles in Los Angeles County. Metro's operations account for just 1.9% of total emissions from passenger transportation by road and rail (excluding Metrolink and Amtrak) in Los Angeles County.

Figure 3: Comparison of Metro's Internal Emissions to External Emissions from Los Angeles County Resident Drivers in 2010



By removing private vehicles from the road, the agency also prevents GHG emissions from entering the atmosphere. In 2010, Metro saved approximately 411,000 MTCO2e from being emitted by displacing vehicle driving.[3] As a result, Metro's net GHG emissions in 2010 were only 65,000 MTCO2e.

The APTA Protocol recognizes additional pathways through which public transportation displaces GHG emissions: by reducing congestion and by fostering more efficient land use patterns. Metro recently completed a study that tests the land-use co-benefit approach for quantifying the reduction in greenhouse gases (GHG) emissions from Metro's transit service.

[3] Los Angeles County Metropolitan Transportation Authority (LACMTA). (2012) Moving Towards Sustainability: 2012 Metro Sustainability Report Using Operational Metrics. Prepared by: ICF International. Los Angeles.

Metro supports one of the nation's highest and most uniform densities per capita in the nation; but this study suggests that the additional GHG savings from transit are difficult to isolate due to Los Angeles' unique land use patterns of development. While the results of this study also suggest that the GHG reduction impact of Metro's services may be up to three times greater than APTA's recommended value, further exploration of quantification techniques specifically for the Los Angeles region is necessary before Metro can account for this GHG credit. It is important to recognize that Metro's modern rail system has existed for only 20 years, a relatively short period of time compared to other transit agencies in New York, Chicago, and Philadelphia. Our near term capital projects are adding at least 236 miles of rail and Bus Rapid Transit lines to our system, as well as possible joint development projects. With the onset of these projects, the GHG reduction benefits from dense land use patterns are expected to grow. Valuation of these GHG credits is currently the subject of national discussion.

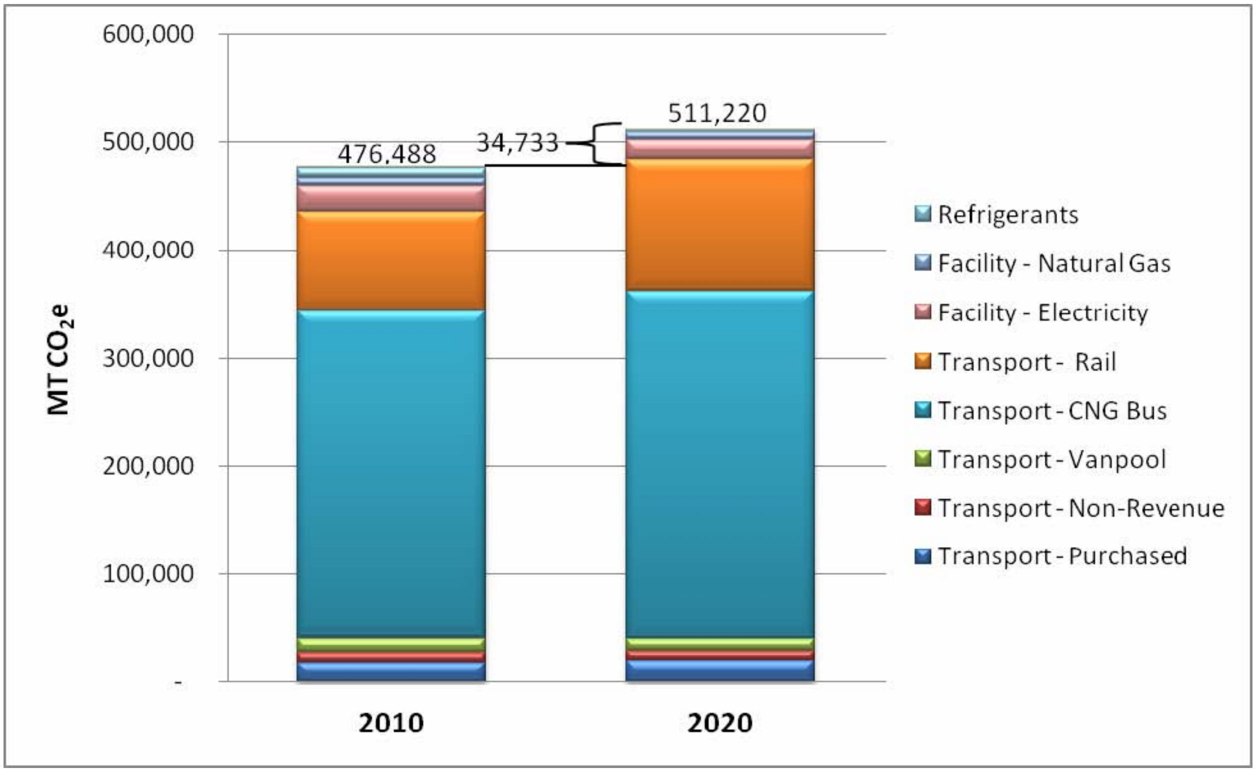
Metro's GHG Emissions: 2020

By 2020, Metro's internal emissions will increase by 34,733 metric tons (MT), or 7%, to 511,220 MT.[4] Figure 4 charts the increase. Much of the increase will come from an expanded rail system. Rail emissions will account for a slightly larger share of total emissions in 2020 than in 2010. An increase in emissions from CNG buses is also forecast, as service expands to accommodate a growing population in Los Angeles County. Emissions from facility electricity use will fall despite an expanding building footprint, due to improvements in energy efficiency and an electricity supply that is becoming less carbon intensive. In total, Metro's transit service, including buses, rail, and vanpools, will account for 95% of GHG emissions in 2020. In 2020, annual boardings are expected to increase to 516 million, up 12% from 2010, and GHG emissions per boarding will fall 4.4%, from 1.04 $MTCO_2e$ per thousand boardings to 0.99 $MTCO_2e$ per thousand boardings.

The 2020 emissions forecast is based on available information about planned changes to Metro's systems, facilities, and vehicles, as well as expected changes to Metro's energy supply. The forecast represents only one possible future for Metro, and is provided here as a reference case. All assumptions used to create the forecast are documented in an Appendix in Section 5.1.

[4] A forecast year of 2020 is used in order to focus on short-term and medium-term actions to reduce emissions. 2020 is also the horizon year for California's GHG reduction goal. Metro's actions can contribute to the achievement of this goal.

Figure 4: Metro Internal Emissions by Source in 2020 (%)[5]



2.2. Metro's Impact on Regional Emissions

In addition to the annual impact of its service on GHG emissions from private vehicles, the agency has enacted policies and made investment choices in recent years that have helped to further reduce regional GHG emissions. These activities, described in Metro's *Greenhouse Gas Emissions Cost-Effectiveness Study* (2010), include:

- **Ridesharing and Transit Pass Programs for Los Angeles Employers—**Metro provides a variety of services and product offerings to employers and educational institutions in Los Angeles County to help them promote carpooling and transit as alternatives to driving alone. Products and services offered include a regional ridematching program, a Guaranteed Ride Home program, ridesharing incentives, special transit passes for employees and students, and outreach to employers and colleges, including marketing, training, and program support. At their current deployment levels, these programs reach around 300,000 employees and students in LA County annually, and reduce around 93,000 $MTCO_2e$ annually. That is equivalent to removing more than 18,000 cars from Los Angeles County's roads.[6]
- **Metro Employee Transit Subsidy Program—**Metro encourages employees to use public transit for their commute trips by subsidizing transit fares for employees who use transit

[5] Water Use, SF6, Refrigerants, and Transport-Diesel/Gasoline Bus sectors have very small contributions to Metro's total emissions. The contributions of these sources are included in the total, but are not separately visible.

[6] The conversion factor for emissions to passenger cars is 5.1 metric tons CO_2e /vehicle /year. From U.S. Environmental Protection Agency (2011), "Calculations and References" http://www.epa.gov/cleanenergy/energy-resources/refs.html

service other than Metro. (All Metro employees have unlimited free access to Metro's transit service.) Currently, approximately 1,500 employees are enrolled in the transit subsidy program. They reduce over 4,800 $MTCO_2e$ annually. That is equivalent to removing more than 940 cars from Los Angeles County's roads. This program could be expanded through more intensive outreach and marketing activities to encourage greater use of both the subsidy and of Metro transit service.

- **Transit Oriented Development—**Metro owns approximately 30 sites adjacent to current and future rail and BRT stations. Many of these sites are prime candidates for mixed use transit oriented development (TOD). A handful of the properties have already been developed as TOD. Generally, properties are developed as primarily residential, with a small retail component. TODs reduce GHG emissions by locating homes and businesses near high quality transit, such that residents and employees on site can take the train or bus and leave their cars at home more often. Mixing of land uses within a TOD also allows residents to walk for some trips to retail and service destinations. There are 8 sites currently under lease to developers. When completed, the projects are expected to reduce 14,600 $MTCO_2e$ annually, or the equivalent of removing more than 2,800 cars from Los Angeles County's roads.
- **Bike-to-Transit Commuter Incentives—**Bicycling is a much quicker way to access transit stops and stations than walking. As a result people are willing to bicycle further to access transit than they would walk. Metro can encourage bicycling to transit by offering financial incentives, such as assistance purchasing a bicycle. Free transit passes offered to those who bike to transit also encourage more biking, as do amenities such as bike lockers, and marketing initiatives. A small pilot program was conducted in Pasadena in 2007. If a similar program were implemented at half of Metro's approximately 60 rail stations, the total GHG reduction would be 650 $MTCO_2e$ annually. That is equivalent to removing 125 cars from Los Angeles County's roads.
- **Bicycle Paths along Transit Corridors—**Integrating bicycle and pedestrian facilities with transit facilities provides a higher multimodal level of service than transit or bicycle/pedestrian facilities alone, allowing travelers to switch more easily between modes and use more than one non-auto mode per trip. Metro Orange Line bike path and associated bicycle amenities are an excellent example. If Metro implemented integrated bike paths, lockers, and other facilities along half of its elevated or at-grade rail system, it could reduce an additional 1,051 to 1,697 $MTCO_2e$ per year. That is equivalent to removing at least 200 cars from Los Angeles County's roads.
- **Vanpools—**The basic premise of a vanpool is that people ride together from home or a common meeting location to an employment center. Metro assists with the formation of vanpools and offers riders a subsidy of up to $400 per van per month. The number of Metro's vanpools has increased dramatically in recent years, from 327 in 2007 to 892 as of February 2010. Based on numbers from February 2010, the annual GHG reduction associated with existing vanpools is about 46,000 $MTCO_2e$ per year, or the equivalent of removing over 9,000 cars from Los Angeles County's roads.

- **Expand Rail and BRT—**Metro's 2030 Long Range Transportation Plan lists 21 potential new fixed guideway transit projects. Proposed projects include extensions to the Gold, Green, and Red Lines, connections between existing lines, and other new transit lines. Expanding fixed guideway systems allows more people to use transit to travel from their homes to places of work, school, and other destinations. The average project in the plan would reduce GHG emissions by 2,700 $MTCO_2e$ annually per mile, if operational today. The highest performing projects would reduce emissions annually by an average 14,700 $MTCO_2e$ per mile. On average, for every mile of fixed guideway built, it would be the equivalent of removing 500 cars from Los Angeles County's roads. The best performing project would be the equivalent of over 2,800 cars.

The estimates of GHG emissions impacts provided above are drawn directly from the *Greenhouse Gas Emissions Cost-Effectiveness Study* (2010), and are provided here as illustrative examples only. These estimates have not been updated for the purposes of this Plan, since the Plan's analytical framework is focused on strategies to reduce operational emissions.

Metro has a number of opportunities to reduce emissions from travel in private vehicles, by building upon the existing programs mentioned above, and by initiating new programs that encourage more walking, biking, carpooling, and use of transit in place of trips in private vehicles. Metro can potentially influence GHG emissions through other regional strategies that it does not directly control, such as those involving Metrolink commuter rail, goods movement, and highway operations. Because these types of strategies affect the entire transportation system of Los Angeles County, they are considered as part of Metro's transportation planning activities.

Metro plans for long term transportation investments and near term transportation demand management programs in a complex policy framework that includes a variety of regional partner agencies. These investments and programs shape travel patterns in the region in conjunction with other factors including land use developments and economic and demographic trends. As such, a more robust framework is needed to analyze and prioritize those types of strategies than the one used in this Plan. As a result, this plan focuses on strategies that would affect Metro's internal operations only. Metro intends to incorporate VMT reducing strategies in a future update of the Plan.

2.3. Reducing Emissions from Metro's Operations

This section identifies a set of measures Metro could implement to reduce its GHG emissions and analyzes those measures for their capacity to reduce emissions. Metro could implement some of the strategies analyzed to achieve a modest GHG reduction goal. The last part of this section outlines steps for the implementation of the measures.

Methodology

There are a large number of potential GHG reduction measures that Metro could use to reduce its emissions. A screening exercise was conducted in order to identify a short list of measures to analyze. The memo describing the screening process and its outcomes is included as an appendix in section 5.2. A brief summary is included here.

The first step in the screening exercise was to identify potential measures from studies conducted by Metro and other transit agencies. A consolidated list of 50 measures was developed. All strategy types that could directly or indirectly reduce emissions were considered, including VMT reduction strategies, vehicle technology and fuels strategies, building and facility energy strategies, renewable energy, water use strategies, and recycling and waste management strategies.

The next step was to assess and rank the measures in terms of benefits, costs, implementation timeframe, and data availability. The highest scoring measures where those considered easy to quantify, having a large potential GHG reduction, a short timeframe for implementation, and relatively low cost per ton of GHGs reduced.

A set of 17 strategies was identified for analysis and potential inclusion in this Plan based on their scores and applicability. The strategies that would offset vehicle miles traveled were subsequently removed from the analysis following a decision to focus just on operational strategies. The next section describes the measures and the analysis conducted on them.

Strategies

Eleven strategies in the areas of vehicle technology, building energy, and water use were selected for further analysis and potential inclusion in the Plan. Most of these measures were analyzed in Metro's *Greenhouse Gas Emissions Cost Effectiveness Study* (2010) and the analysis for this plan built on the work done in that study. Each measure and its analysis approach are described briefly below and the strategy impacts are summarized in the next section. A more detailed description of the analysis methodology for each strategy is included as an appendix in section 5.3.

All strategies were analyzed over a consistent timeframe, 2012 to 2020. This timeframe is used to allow comparison of strategies' impacts with Metro's GHG forecast. The impacts of strategies are presented in terms of the key metrics of GHG emission reduced, costs to Metro, and cost effectiveness.

GHG emissions reduced are compared at three points in time: 2014, 2020, and cumulative reductions occurring between 2012 and 2020. Reductions in 2014 reflect the potential near term impacts of strategies, while reductions in 2020 show what Metro can achieve with more time to implement strategies and allow for comparisons with Metro's forecast GHG emissions. Since GHG emissions have cumulative impacts on our atmosphere, cumulative reductions from the present year (2012) to the horizon year (2020) are also provided.

Costs of strategies are provided as three separate metrics. Upfront investment costs represent the initial investment required to implement any strategy—typically comprising capital investment costs in new vehicles or equipment. Many strategies have additional cost impacts after an initial investment is made—including maintenance and replacement costs, labor costs, disposal costs, and cost savings on electricity and fuel. All costs and savings accruing over multiple years are represented as the net costs from 2012-2020, using a 5% discount rate. In addition, costs were calculated on a lifecycle basis to capture the full value of some investments and for consistency with the cost evaluation framework often used by Metro's Board and management. Unlike the net costs (which were calculated over the period 2012-2020 for all strategies), lifecycle cost was calculated for the estimated lifetime of the vehicle/equipment, which varies by strategy. For measures that save Metro money over their lifetime, we also calculated the payback period for the strategy. Lifecycle costs were generally calculated for a single unit (e.g. per bus or per facility); GHG reductions and strategy costs were calculated assuming a specific phasing of implementation for the measures. All costs represented are costs to Metro only, and do not include cost impacts to transportation users or other public agencies.

Cost effectiveness, or dollars per metric ton of GHG emissions reduced ($/ton), compares the cost and emissions impacts of strategies. It provides a metric of the value for money that each strategy provides in terms of GHG reductions. Cumulative reductions and net costs are used to calculate cost effectiveness.

In the tables reported with each strategy, a positive value for the cost indicates a cost outlay for Metro and negative values indicate cost savings for Metro. Negative values for cost effectiveness indicate strategies where Metro saves money over the analysis period.

Vehicle Technology Strategies

- **On-board Storage of Regenerative Braking Energy**—Metro can use regenerative braking on its trains to capture and reuse the electricity produced during dynamic braking. Metro light rail and heavy rail cars already have the ability to regenerate energy and feed it back to the line, to be used by other vehicles running in the same substation section. They also power their own auxiliary loads while in dynamic braking; however, the re-captured energy is a very low percentage of the total brake energy. The rest of the brake energy is burned off through brake resistors, typically located on the top of the car. Onboard storage devices would allow Metro to capture this waste energy and release it again when needed during the next acceleration cycle.

  For the purposes of this Plan, it was assumed that 25% of existing railcars would be retrofitted with the technology by 2014 and 100% of the fleet (both existing and new vehicles) would have the technology by 2020. While the strategy as implemented in the analysis involves an upfront cost to Metro, Metro would save money over the lifetime of the technology. Between 2012 and 2020 this strategy would reduce 96,411 $MTCO_2e$ at a cost of $180 per $MTCO_2e$.

- **Wayside Energy Storage Substations (WESS)—**WESS capture energy released when a rail car unit decelerates and then release the energy back into the system when required. In contrast to on-board regenerative braking technology, in which a battery pack or storage device is installed on the railcar itself, wayside storage relies on stationary systems installed within each electrical substation (at each station or mile of track).

  For the purposes of the Plan, it is assumed that one station would have this technology in place by 2014 and that 30 stations (approximately half of Metro's current stations) would have WESS systems by 2020. Between 2012 and 2020 this strategy would reduce 17,289 $MTCO_2e$ at a cost of $2,774 per $MTCO_2e$.

- **Mobile Air Conditioning Replacement—**The refrigerant currently used in Metro's bus fleet is a potent GHG, with over 1,400 times the capacity of carbon dioxide to trap heat in the atmosphere. Newer refrigerants with much lower global warming potentials have been developed and are seeing their first applications in transportation. Although starting in the automotive sector, the refrigerants are expected to be available for other vehicles, including buses, in the near future. It is expected that the new refrigerant will initially be used in new units primarily, with limited retrofits. For the purposes of this Plan, it is assumed that the new refrigerant will be installed in new buses only, starting in 2014.

  The refrigerants used in railcars are also potent greenhouse gases, but alternative refrigerants are not as well developed for railcar air conditioning systems. For this reason railcars were excluded from this strategy's analysis. Between 2012 and 2020 this strategy would reduce 353 $MTCO_2e$ at a cost of $3,130 per $MTCO_2e$.

- **Gasoline-Electric Hybrid Buses–**Metro can reduce GHG emissions by replacing conventional CNG buses with gasoline hybrid electric (GHE) buses, which are more fuel-efficient. GHE buses operate using a gasoline engine in tandem with a battery pack and electric motor. GHE buses achieve better fuel efficiency than CNG buses, but the actual GHG emission reductions are limited because gasoline is more carbon intensive than CNG. The cost effectiveness of this strategy is also affected by the prices Metro pays for gasoline and CNG, which can fluctuate widely; CNG is currently cheaper than gasoline.

  The analysis of this strategy and the next distinguishes between tank-to-wheels and well-to-wheels GHG emissions for reformulated gasoline and natural gas. The well-to-wheels GHG emissions for transportation fuels account for so-called upstream activities. For gasoline these activities include extraction of petroleum, refining the product, and transportation at various points along the supply chain; for natural gas, these activities include resource recovery, transmission, and compression for use in vehicles. Emissions from the manufacture and the disposal of the vehicle are not included in the well-to-wheels emissions. Tank-to-wheels emissions are only those from the tailpipe of the vehicle, created by combustion of the fuel.

  For the purposes of this Plan it is assumed that all replacement and new buses added to the fleet between 2012 and 2020 are GHE buses. On a tank-to-wheels basis, between 2012 and 2020 this strategy would reduce 76,826 $MTCO_2e$ at a cost of $4,922 per $MTCO_2e$. If analyzed on a well-to-wheels basis, the emission reductions from this strategy would increase by nearly 25%.

- **Biomethane in CNG Buses—**Metro has the potential to incorporate biomethane into its bus fleet as a strategy to reduce GHG emissions. Biomethane is generally sourced from the anaerobic digestion or gasification of organic matter from landfills or dairy farms. The captured product is subsequently cleaned and scrubbed of impurities for use in applications ranging from transportation to power generation. When biomethane is properly refined, it can be used in CNG buses without modifications to the vehicles.

  On a tank-to-wheels emissions basis, biomethane is identical to conventional CNG; however, when the upstream emissions are included, biomethane has the potential to reduce GHG emissions significantly. The upstream portion of the lifecycle emissions of biomethane results in a significant carbon credit because the captured methane would have been flared on site rather than captured for use. As a result, the well-to-wheels emissions factor for biomethane from landfills, as reported by the California Air Resources Board, is nearly 85% lower than that of conventional CNG.

For the purposes of the Plan, it is assumed that Metro would be able to achieve about 9% displacement of CNG with biomethane by 2015 and 42% displacement by 2020. This is an aggressive displacement scenario, assuming that technological breakthroughs lead to increased production in California, and that there are sufficient incentives in place to use biomethane in the transportation sector instead of the power generation sector. Biomethane is likely to come at a premium versus conventional CNG, but the costs for biomethane are currently unknown. For a low cost scenario, we assumed that biomethane would be two times the cost of conventional natural gas; in a high scenario, we assumed that biomethane would be three times the cost of conventional natural gas. On a well-to-wheels basis, between 2012 and 2020 this strategy would reduce 528,555 $MTCO_2e$ at a cost of \$174 per $MTCO_2e$ in the low cost scenario or \$349 per $MTCO_2e$ in the high cost scenario.

Building Energy Strategies

- **Facility Lighting Upgrades—**Metro can replace existing lighting and other energy end-use equipment in its facilities with more efficient and cost-effective equipment. Audits of two representative Metro division facilities (Divisions 10 and 18) indicate that older, less efficient lighting is used throughout those facilities. Metro can replace those lights with longer-lasting, more efficient lights. The Cost Effectiveness Study analyzed the potential for Metro to replace T12 fluorescent lights and metal halide lights. T12s could be replaced with more efficient T8 fluorescent lights. Metal halide lights could be replaced with LEDs (scenario 1) or with more efficient metal halide lights (scenario 2).

  For the purposes of this Plan, we assume that all identified fluorescent and metal halide lighting in Metro's Divisions would be retrofitted by 2014. To date, Metro has retrofitted approximately 20% of the linear fluorescent lights across all of its Divisions. Between 2012 and 2020, scenario 1 would reduce 71,621$MTCO_2e$ and scenario 2 would reduce 46,226 $MTCO_2e$; both scenarios save Metro money over the analysis period.

- **Expand Use of Renewable Energy—**Metro can develop new renewable energy installations to reduce its dependence on traditional electricity sources. In this analysis, Metro would expand its existing renewable energy generation capacity by 1.3 MW. As an example, the Cost Effectiveness Report analyzed two possible solar photovoltaic projects, one alongside the I-405 freeway and one along the Metro Orange Line. This analysis uses those same projects. Between 2012 and 2020 this strategy would reduce 4,467 $MTCO_2e$ at a cost of \$2,303 per $MTCO_2e$.

- **Retrofit Lighting in Red Line Tunnel—**This strategy reduces GHG emissions, energy usage, and labor hours by installing more efficient and longer lasting lighting fixtures in the 22-mile Red Line subway tunnel. Metro has selected an LED (light emitting diode) lighting technology to be used in the Red Line Tunnel. For the purposes of this Plan, it is assumed that all of the 74 watt two-lamp T8 fixtures currently installed in the Red Line Tunnel would be replaced by 2014 with linear style LEDs of 35 watts per two-lamp fixture. Between 2012 and 2020 this strategy would reduce 5,783 $MTCO_2e$ and save Metro money over the analysis period.

Water Use Strategies

- **Municipal Recycled Water for Bus Washing—**Metro can use recycled water for the preliminary rinse and wash stages for bus washing. Municipal recycled water systems are already in place in many parts of the Metro service area and can provide an alternative, less energy-intensive source of water for bus washing activities. This strategy reduces both GHG emissions and the consumption of potable water, which also reduces Metro's water costs. This strategy was analyzed assuming municipal recycled water would be used for all bus washing facilities. Between 2012 and 2020 this strategy would reduce 941 $MTCO_2e$ and save Metro money over the analysis period.
- **Extension of Bus Wash On-Site Water Reclamation—**Metro can alter its bus washers and operational procedures to capture more runoff water for reuse on-site. Metro's bus washers currently capture run-off through floor grates within the bus washing bays. Air blowers within the bays are used to enhance runoff while the bus is over the grates. However, runoff continues once the bus has moved off the floor collection grates. The grates could be extended an additional 50 feet to capture more runoff. Procedurally, the maximum speed limit through the washers should be strictly enforced and the air blowers should be activated every time a bus comes through to ensure maximum runoff capture. This strategy was analyzed assuming all Metro bus washing facilities would have their floor grates extended. Between 2012 and 2020 this strategy would reduce 544 $MTCO_2e$ and save Metro money over the analysis period.
- **Low Water Sanitary Fixtures—**Metro can replace its existing standard flow sanitary fixtures with high efficiency, low flow models. This strategy has the potential to save a considerable amount of water, reducing water and water heating costs to Metro while reducing the emissions associated with the conveyance, treatment, and heating of water. This strategy was analyzed assuming all Divisions would have their sanitary fixtures replaced with low water models. Between 2012 and 2020 this strategy would reduce 424 $MTCO_2e$ and save Metro money over the analysis period.

Results of Strategies

Individual Strategy Summary

Table 2 ranks the strategies from greatest emissions reduced to least emissions reduced on a cumulative basis. The 'Use of Biomethane in CNG Buses' has very high reductions thanks to the large carbon credit associated with the lifecycle emissions of biomethane compared to conventional CNG. All of these reductions occur in the upstream portion of the fuel cycle. Therefore the strategy reduces emissions that are not currently counted in Metro's GHG inventory. The vehicle technology strategies generally offer larger GHG emission reductions than the building energy and water strategies, since more than 90% of Metro's GHG emissions are from its vehicles. Due to the need for phased implementation, many of the vehicle technology strategies substantially increase their annual GHG emission savings over the period of analysis, from 2012 to 2020.

Table 2: GHG Emissions Impact by Strategy

Strategy	CO_2e reductions (MT)		
	2014	2020	Cumulative, 2012–2020
Use Biomethane in CNG Buses (well-to-wheels impacts)	26,291	125,744	528,555
On-board Railcar Braking Energy Storage	6,288	18,616	96,411
Gasoline-Electric Hybrid Buses (tank-to-wheels impacts)	5,066	15,479	76,826
Building Indoor Lighting Upgrades: LEDs	2,890	2,890	71,621
Building Indoor Lighting Upgrades: Efficient Metal Halides	1,722	1,722	46,226
Wayside Energy Storage Substation (WESS)	836	3,745	17,289
Retrofit Lighting in Red Line Tunnel	699	529	5,783
Expand Use of Renewable Energy	536	416	4,467
Municipal Recycled Water For Bus Washing	105	105	941
Extension of Bus Wash On-Site Reclamation	60	60	544
Low Water Sanitary Fixtures	47	47	424
Mobile Air Conditioning Replacement	0	101	353

Table 3 ranks the cost impacts of each strategy in net terms, from greatest savings to greatest cost. Net cost is a measure of the total financial impact of a strategy, including costs and savings over multiple years. Negative values indicate strategies that save Metro money over the analysis period. The net cost of several of the strategies analyzed in this document would continue to improve after 2020, as continuing cost savings on fuel or electricity offset the initial investment costs. These longer term savings are captured in Table 4, which shows the lifecycle costs for each strategy on a per unit basis. These two tables show that the building energy and water strategies tend to save money for Metro in net terms, while many of the vehicle technology strategies involve large net costs. All costs represented are costs to Metro only, and do not include cost impacts to transportation users or other public agencies.

Table 3 also provides upfront investment costs for all strategies. Upfront investment costs represent the initial investment required to implement any strategy—typically comprising capital investment costs in new vehicles or equipment. They do not include subsequent ongoing cost impacts—including maintenance and replacement costs, labor costs, disposal costs, and cost savings on electricity and fuel. Most of the strategies involve an upfront cost which is then paid back in part or in full in subsequent years, as reflected in the net cost. Exceptions to that rule are the biomethane strategy and the gasoline hybrid electric buses. Biomethane incurs no upfront costs, but premiums are paid annually for biomethane. Hybrid buses do not generate annual cost savings after the initial upfront investment, because Metro pays a premium on gasoline over CNG.

Table 3: Cost Impacts by Strategy

Strategy	Upfront Investment Cost*	Net Costs from 2012 to 2020*
Building Indoor Lighting Upgrades: LEDs	$6,191,735	-$5,560,951
Building Indoor Lighting Upgrades: Efficient Metal Halides	$2,513,748	-$5,410,982
Extension of Bus Wash On-Site Reclamation	$120,000	-$1,292,876
Municipal Recycled Water For Bus Washing	$135,000	-$536,769
Retrofit Lighting in Red Line Tunnel	$979,296	-$420,343
Low Water Sanitary Fixtures	$252,320	-$385,161
Mobile Air Conditioning Replacement	$1,505,149	$1,104,988
Expand Use of Renewable Energy	$13,500,000	$10,288,561
On-board Railcar Braking Energy Storage	$52,400,000	$17,312,217
Wayside Energy Storage Substation (WESS)	$62,400,000	$47,963,477
Use Biomethane in CNG Buses: Low Cost Scenario	$0	$92,216,943
Use Biomethane in CNG Buses: High Cost Scenario	$0	$184,433,886
Gasoline-Electric Hybrid Buses	$270,000,000	$378,171,646

** Positive numbers are a net outlay and negative numbers are a net savings*

NB: All costs represented are costs to Metro only, and do not include cost impacts to transportation users or other public agencies.

While the costs reported in Table 3 consider only the time period from 2012 to 2020 and factor in implementation timing of the individual measures, Table 4 reports the net costs or savings for the lifecycle of the strategy for an individual unit (e.g. per bus or per facility).The lifetime of the strategies range from 3 years to 40 years. The payback period is the time, in years, that it would take for annual net savings from the investment to offset the upfront investment costs. Looking at lifecycle costs, on-board railcar braking energy storage actually saves Metro money over the railcar lifetime, though in the 2012-2020 analysis timeframe, the strategy would cost Metro more than it saves. All of the building energy and water saving strategies would payback within 1 to 3 years. Under the assumptions used in this analysis, most of the vehicle strategies do not payback within the lifetime of the technologies.

Table 4: Lifecycle Costs and Payback Period by Strategy

Strategy	Lifecycle Costs*	Lifecycle Cost Unit	Investment Lifetime	Payback Period
Low Water Sanitary Fixtures	-$865,382	For all bus and rail facilities	20 years	3 years
Retrofit Lighting in Red Line Tunnel	-$487,692	For all tunnel fixtures	4 years	2 years
Building Indoor Lighting Upgrades: LEDs	-$321,265	For all Divisions	6 years	2 years
Extension of Bus Wash On-Site Reclamation	-$274,237	Per bus washing facility	40 years	1 year
Building Indoor Lighting Upgrades: Efficient Metal Halides	-$133,750	For all Divisions	3 years	1 year
Municipal Recycled Water For Bus Washing	-$123,894	Per bus washing facility	40 years	1 year

Strategy	Lifecycle Costs*	Lifecycle Cost Unit	Investment Lifetime	Payback Period
On-board Railcar Braking Energy Storage	-$78,619	Per railcar	20 years	7 years
Mobile Air Conditioning Replacement	$546	Per bus	13.5 years	n/a
Use Biomethane in CNG Buses: Low Cost Scenario	$286,079	Per bus	13.5 years	n/a
Gasoline-Electric Hybrid or CNG Hybrid Buses	$355,688	Per bus	13.5 years	n/a
Use Biomethane in CNG Buses: High Cost Scenario	$572,159	Per bus	13.5 years	n/a
Wayside Energy Storage Substation (WESS)	$1,528,155	Per substation	20 years	n/a
Expand Use of Renewable Energy	$8,886,753	Per 1.3 MWh project	30 years	n/a

** Positive numbers are a net outlay and negative numbers are a net savings. Strategies that do not payback during the lifetime of the investment (have positive lifecycle costs) have a payback period of "n/a" (not applicable).*

NB: All costs represented are costs to Metro only, and do not include cost impacts to transportation users or other public agencies.

Table 5 ranks the strategies by their cost-effectiveness in terms of net cost per metric ton of CO_2-equivalents reduced (cumulative over the analysis period 2012-2020). For strategies that result in a *net savings* to Metro, the cost effectiveness ratio can be misleading and should not be compared across strategies. In particular, it should not be assumed that a strategy with a $/ton ratio that is "more negative" than another is necessarily better. Consider, for example, two strategies that each save $1,000. Strategy A eliminates 10 tons of emissions, while Strategy B eliminates 20 tons of emissions. In this case, Strategy B is preferable, even though its cost effectiveness (-$50/ton) is closer to zero than that of Strategy A (-$100/ton).

Of the strategies that involve net costs to Metro, biomethane and on-board railcar braking energy storage are relatively cost effective strategies. Under the assumptions used in this analysis, these strategies would reduce emissions for less than $350 per ton of CO_2e. Expanding renewable energy generation, WESS, replacing refrigerants in buses, and purchasing GHE buses are less cost effective. Each of these strategies costs more than $2,300 per ton of CO_2e reduced.

Table 5: Cost Effectiveness by Strategy (2012-2020)

Strategy	GHG Reduction Cost Effectiveness ($/MT)*
Extension of Bus Wash On-Site Reclamation	-$2,378
Low Water Sanitary Fixtures	-$907
Municipal Recycled Water For Bus Washing	-$570
Building Indoor Lighting Upgrades: Efficient Metal Halides	-$117
Building Indoor Lighting Upgrades: LEDs	-$78
Retrofit Lighting in Red Line Tunnel	-$73
Use Biomethane in CNG Buses: Low Cost Scenario	$174
On-board Railcar Braking Energy Storage	$180
Use Biomethane in CNG Buses: High Cost Scenario	$349
Expand Use of Renewable Energy	$2,303
Wayside Energy Storage Substation (WESS)	$2,774
Mobile Air Conditioning Replacement	$3,130
Gasoline-Electric Hybrid Buses (tank-to-wheels)	$4,922

** Negative numbers indicate a net savings*

NB: All costs represented are costs to Metro only, and do not include cost impacts to transportation users or other public agencies.

Strategy Packages

Metro is most likely to implement a package of strategies that reduce GHG emissions. To demonstrate the total impact that multiple strategies could have together, four potential packages of strategies were analyzed, as follows:

1. **Short-Term Cost Saving Strategies—**These are strategies that will provide net savings to Metro by 2020 and are ready for implementation in the near term using readily available methods.
2. **Short-Term and Mid-Term Strategies—**All strategies that are ready for implementation in the near term using available methods, as well as additional strategies that are appropriate for wider implementation pending the results of demonstration projects.
3. **All Strategies with Tank-to-Wheels Benefits—**All strategies that would reduce GHG emissions currently counted as part of Metro's GHG inventory. (This excludes the biomethane strategy).
4. **All Strategies with Well-to-Wheels Benefits—**All strategies that would reduce GHG emissions included or not included in Metro's GHG inventory, including the biomethane strategy. (GHE buses are excluded from this package, since a full implementation of the biomethane strategy is not compatible with expanding use of GHE buses).

Details about the implementation status and potential for each strategy are provided in a subsequent section. Table 6 details the strategies included in each package.

Table 6: Strategy Packages

Strategy	Short-Term Cost Saving Strategies	Short-Term and Mid-Term Strategies	All Strategies with Tank-to-Wheels Benefits	All Strategies with Well-to-Wheels Benefits*
Building Indoor Lighting Upgrades	X	X	X	X
Municipal Recycled Water for Bus Washing	X	X	X	X
Extension of Bus Wash On-Site Reclamation	X	X	X	X
Low Water Sanitary Fixtures	X	X	X	X
Retrofit Lighting in Red Line Tunnel	X	X	X	X
On-board Railcar Braking Energy Storage		X	X	X
Expand Use of Renewable Energy		X	X	X
Wayside Energy Storage Substation (WESS)		X	X	X
Mobile Air Conditioning Replacement			X	X
Gasoline-Electric Hybrid Buses			X	
Biomethane				X

** Excludes GHE buses since a full implementation of the biomethane strategy is not compatible with expanding use of GHE buses*

Table 7 provides the total impacts that each package would have in terms of GHG emissions reduced, cost, and cost effectiveness. Packages 2, 3, and 4 include both On-board Railcar Braking Energy Storage and WESS, which save energy and emissions through similar mechanisms. GHG reductions from the WESS strategy are conservatively excluded from these packages, since WESS' GHG impacts are unknown when the strategy is implemented in conjunction with on-board regenerative braking. By implementing just Short-Term Cost Saving Strategies, Metro could reduce its forecast emissions in 2020 by 0.6% and save $8 million. By implementing Short-Term and Mid-Term Strategies, Metro could reduce its forecast emissions by 4.3% at a net cost of roughly $67 million. Implementing All Strategies with the exception of biomethane would reduce Metro's 2020 emissions by 7.4% at a net cost of $447 million. Implementing All Strategies including biomethane (but excluding GHE buses) would reduce Metro's forecast emissions by 28.9% at a net cost of $207 million. That result assumes that Metro takes credit for emissions reductions not currently counted in the GHG inventory, because they occur upstream in the fuel cycle.

Table 7: Results of Strategy Packages

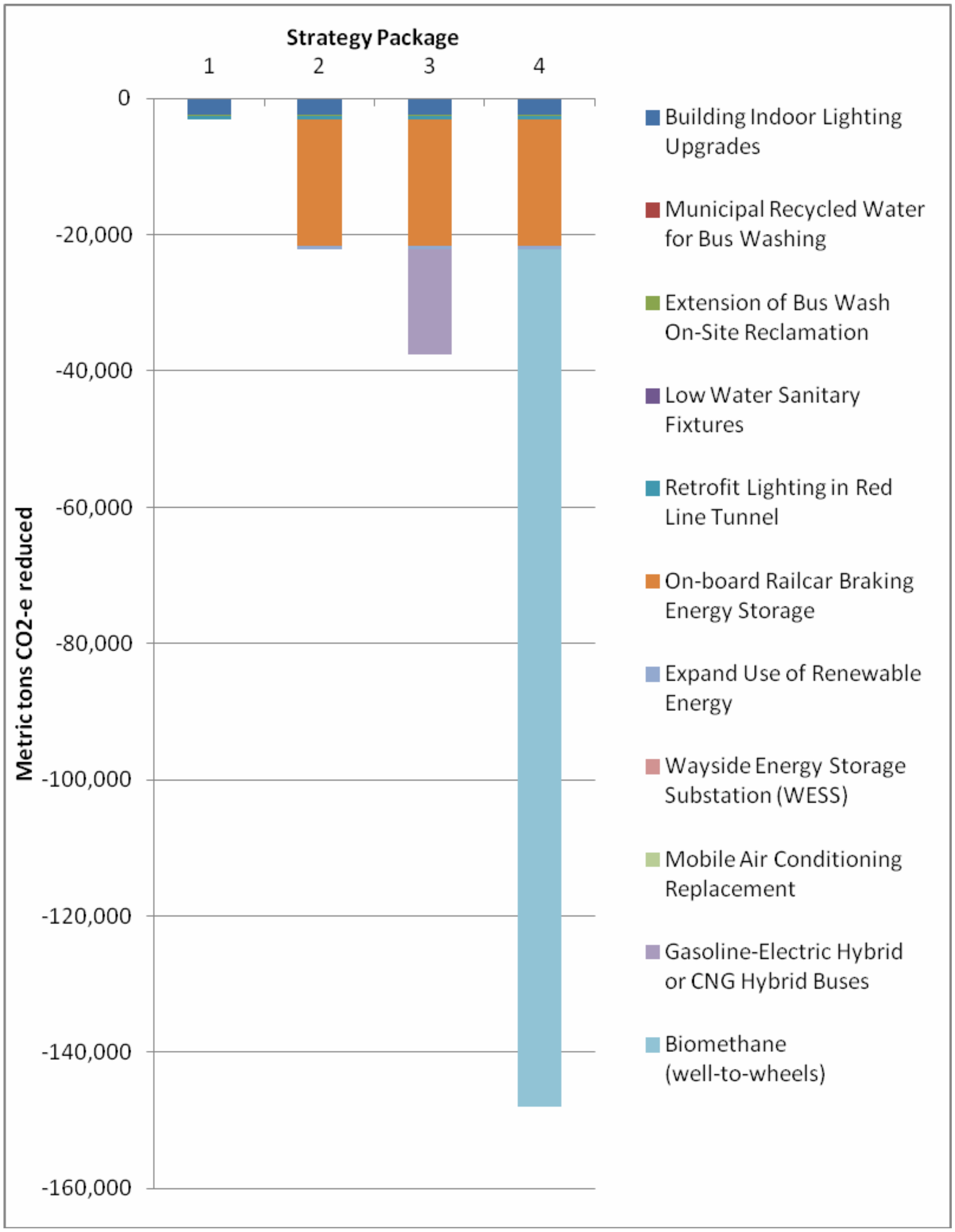
Package	CO2e Reductions (MT)			Cost Impacts		Reduction in Forecast GHG emissions in 2020	Reduction in GHG emissions per boarding from 2010 to 2020
	2014	2020	Cumulative, 2012-2020	Net Cost*	Cost Effective-ness ($/ton reduced)*		
1. Short-Term Cost Saving Strategies	3,217	3,048	66,616	-$8,121,116	-$122	0.6%	5.0%
2. Short-Term and Mid-Term Strategies	10,042	22,080	167,494	$67,443,140	$403	4.3%	8.6%
3. All Strategies with Tank-to-Wheels Benefits	15,107	37,660	244,673	$446,719,774	$1,826	7.4%	11.5%
4. All Strategies with Well-to-Wheels Benefits	36,332	147,925	696,402	$206,873,542	$297	28.9%	32.1%

** Negative numbers indicate a net savings. Costs represent the impact of strategies examined in this plan, and do not include any costs for planned actions included in Metro's 2020 GHG emissions forecast, such as system expansion.*

NB: All costs represented are costs to Metro only, and do not include cost impacts to transportation users or other public agencies.

Figure 5 compares the total emissions reduced by each package of strategies in 2020. Many of the strategies have relatively small GHG emissions impacts. The impacts of the biomethane strategy notably dwarf the impacts of many of the other strategies.

Figure 5: GHG Emissions Reduced in 2020 by Strategy Packages



Proposed Goals

As demonstrated above, Metro could meet a goal of reducing internal GHG emissions by 0.6% in the year 2020 using cost effective strategies. This is equivalent to reducing Metro's GHG emissions per boarding by 5.0% from 2010 to 2020.

Without taking any of the actions suggested in this plan, Metro's GHG emissions per boarding will fall by 4.4% from 2010 to 2020. This reduction will occur as a result of planned system expansions, which will draw more passengers, and an electricity supply that is shifting towards more renewable energy.

Proposed Goal: Reduce Metro's GHG emissions per boarding by 5.0% from 2010 to 2020.

Actions Required to Meet Proposed Goal

Metro has multiple pathways to meet the proposed goal, including:

- Implement Short-Term Cost Saving Strategy Package – Implementing this package of strategies would save Metro a net $8.1 million between now and 2020, as calculated above. Metro is already implementing some of these strategies. The retrofit of Red Line tunnel lighting is expected to begin in 2012. Upgrades to facility lighting are ongoing. Metro has currently retrofitted lighting in about 20% of its facilities. These retrofits could easily be completed by 2020. To implement the remainder of this package, Metro would need to expand its current water savings strategies, and ensure their proper operation. (Further detail on implementation steps is provided in a subsequent section).
- Partially Implement Short-Term and Mid-Term Strategy Package – Implementing this package in full would exceed the proposed GHG reduction goal. It is likely that Metro will have two WESS projects operational, using existing grant funding, by 2020. Metro is already planning to construct several new solar photovoltaic projects on facilities. Metro could attain the proposed goal by implementing the two WESS projects, retrofitting the Red Line tunnel lighting, installing 0.5 MW of additional solar photovoltaic capacity, and completing facility lighting upgrades by 2020.

In studying other GHG reduction options, Metro may identify other preferred strategies that also meet the goal. For example, fueling just 60 of Metro's CNG buses with biomethane alone would meet the proposed goal.

Implementation Steps for Strategies

The strategies analyzed in this plan are in different stages of implementation, ranging from those already being implemented to those for which further technological advances are needed before they are fully viable. This section addresses the status of the strategies, the barriers to their implementation and uncertainties around current analyses, and action steps to move these strategies forward.

On-board Storage of Regenerative Braking Energy

- **Implementation Status—**Metro has had contact with a manufacturer of an on-board storage retrofit technology, ABB Technologies. The agency plans would like to include on-board storage technology in new rail cars going forward. This measure is being analyzed in a separate Metro study, the Sustainable Rail Plan.
- **Barriers to Implementation (other than costs)—**Finding space to install the unit is one potential constraint. Energy storage units also add weight to rail cars, which affects vehicle

performance and increases energy consumption per car. Installing energy storage devices on-board requires rail cars to be taken out of service for any maintenance and repair of energy storage units.

- **Key Uncertainties—**There is some uncertainty about the amount of electricity savings that would be achieved, especially in conjunction with other energy storage technologies.

  According to the manufacturer, the technology effectiveness will vary greatly depending on the drive profile of each rail car—specifically the amount of braking and acceleration used along the route to stop at stations and overcome grades. A more precise method of calculating costs and benefits would use need to investigate how much energy is currently being regenerated and absorbed by other vehicles on the line in regular revenue service. Such simulations would include current service schedules with all vehicles operating along a reference line.

  Metro has other options for increasing the amount of regenerative braking energy reused within its system. These include the use of Wayside Energy Storage Substations (WESS), another strategy included in this plan, and the installation of jumpers in the electrical transmission systems to allow more of the currently regenerated energy to be reused. The best approach for Metro, considering lifecycle cost, energy savings, and operational constraints, may be one or a combination of these strategies.

  Existing examples of on-board storage are still in testing. One example of such a systems is Mannheim Germany, which started extensive data gathering about 10 years ago with a Bombardier unit on one of their light rail vehicles. Recently, TriMet (Portland, Oregon) installed one unit for test purposes also on one of their light rail vehicles. The technology has not been demonstrated at the scale of Metro’s system.

- **Related Plans—**Metro’s Sustainable Rail Plan (in process) will consider the uncertainties and implementation barriers for this strategy.

- **Action Steps (e.g. current and future studies, form working groups)—**
  - Analyze the potential cost and energy impacts of this strategy in greater detail, including simulations for an individual rail line. Compare this strategy to other strategies that reuse regenerative braking energy, both separately and in conjunction with this strategy. (Metro’s Sustainable Rail Plan will address some of these needs).
  - Establish a working group to analyze this strategy and other energy saving opportunities in Metro’s rail system. (Metro’s Sustainable Rail Plan is establishing a working group).
  - Consider piloting the retrofit technology on a single line.
  - Consider piloting the technology in new vehicles on a single line.

Wayside Energy Storage Substations (WESS)

- **Implementation Status—**Metro has begun a WESS pilot project, using a flywheel technology, funded through a grant from the Federal Transit Administration. The Red Line Westlake Energy Storage System will capture and release energy at the Westlake at-grade rail station. Metro has issued a request for proposals for the design and construction of this system as of early 2012 and expects the pilot system to be operational in 2014. Metro also has an opportunity for a second WESS project on Metro's Gold Line, funded by a grant from the South Coast Air Quality Management District.

- **Barriers to Implementation (other than costs)—**Finding space to install the WESS unit in existing electrical substations is one potential constraint.
- **Key Uncertainties—**There is some uncertainty about the amount of electricity savings that would be achieved, especially in conjunction with other energy storage technologies. Costs to maintain the system are also unknown, and were not included in the analysis.

  Metro's feasibility study of WESS in 2008-09 indicated that the technology's effectiveness will vary depending on the specific operating characteristics of rail line segments. There are also differences in how WESS might be applied to new construction and to retrofit situations. The retrofit scenario was analyzed in this plan; there are potential capital and maintenance cost savings associated with incorporating WESS into rail lines as part of their design.

  Metro has other options for increasing the amount of regenerative braking energy reused within its system. See implementation steps for On-board Storage of Regenerative Braking Energy, above.
- **Related Plans**—Metro's Sustainable Rail Plan (in process) will consider the uncertainties and implementation barriers for this strategy.
- **Action Steps**
  - Monitor the costs and operation of the pilot WESS system once installed and operational.
  - Analyze the potential cost and energy impacts of this strategy in greater detail, including simulations for an individual rail line. Compare this strategy to other strategies that reuse regenerative braking energy, both separately and in conjunction with this strategy. (Metro's Sustainable Rail Plan will address some of these needs).
  - Establish a working group to analyze this strategy and other energy saving opportunities in Metro's rail system. (Metro's Sustainable Rail Plan is establishing a working group).
  - Explore the option of including WESS in the design and construction of new facilities. The earlier feasibility study by Metro noted that line construction costs could be reduced if WESS installations reduced the need for substations, and those stations may also have lower maintenance costs.

Replace Refrigerant in Metro's Buses

- **Implementation Status**—Metro is monitoring the development of new refrigerants for buses and railcars, but no new refrigerants are currently being pursued.
- **Barriers to Implementation (other than costs)**—New refrigerants for railcars and buses are still in development. The alternative refrigerant for buses analyzed in this strategy, HFO-1234yf, is still a new technology and not yet been approved for use in buses and other heavy-duty uses. In addition, due to lower demand and patent issues, the refrigerant is

expected to have limited availability for several years to come. Metro may have difficulty procuring the refrigerant until production increases.

For railcars, the best alternative refrigerant technology is not yet clear.

- **Key Uncertainties**—It is still unclear what replacement refrigerants Metro should use in its buses and railcars. Metro would prefer to have a drop-in replacement for all its vehicles, but at this time only buses appear to have a potential drop-in replacement. Whatever technology is selected, it is likely that in the near term the refrigerant will only be available in new buses and railcars. However, this strategy would have the most impact as a replacement refrigerant in the current bus fleet. New buses are being equipped with refrigeration units that have smaller charges and almost no leakage. These units will greatly reduce emissions from refrigerants even without new refrigerants.

  There are known alternative refrigerants for buses that are beginning to be used in new passenger cars. There is only one known test of the new refrigerant HFO-1234yf in urban buses in Spain. That study found that the new refrigerant matched the efficiency of the current refrigerant (R-134a) only when an additional heat exchanger unit was added to the air conditioning system. There will be a need for new service equipment to recharge systems using the new refrigerant, in order to avoid cross-contamination of the old and new refrigerants. The cost of that equipment is unknown, but is expected to decrease as the new refrigerant comes into more widespread use in the automotive industry.

  At this time the most likely alternative for railcars appears to be R-744c (CO_2), which would require replacement of the existing air conditioning systems. There are concerns with both the higher pressures required for R-744c and with the performance of those systems in higher ambient temperatures. Systems are being tested in Germany currently, but more widespread use appears to be several years off. This technology has also been tested in buses in Germany, raising the possibility that both rail and buses could eventually use the same refrigerant.

  Maintenance staff may need training before servicing systems using the new refrigerant. If retrofits are pursued, staff involved in rehabilitating buses and railcars may need training in installing the new systems.

- **Related Plans**—None
- **Action Steps**
  - For buses
    - Work with bus manufacturers to develop systems with the new refrigerant. Possibly serve as a pilot site for testing the new systems.
    - Monitor the cost of the refrigerant and service equipment. The currently high price of HFO-1234yf refrigerant is expected to fall substantially over the next decade.
    - Retrofit the existing bus fleet after new refrigerant has been tested and the possibility of its use as a drop-in replacement is better understood. Refrigerant costs should also be lower at that time, making this approach more cost-effective.

- Railcars
  - Monitor the development of new mobile air conditioning technology for railcars. As for buses, any new refrigerant would probably be first available in new cars and only later as a retrofit.

Gasoline-Electric Hybrid Buses

- **Implementation Status**—Metro currently operates six gasoline hybrid electric (GHE) buses. Metro is pursuing zero emission and super low emission buses in the near future that may offer alternative technologies, such as fuel cell, battery electric, high-efficiency CNG, or hybrid vehicles.
- **Barriers to Implementation (other than costs)**—There have been technical difficulties in keeping the GHE buses operational due to unique custom components that take longer to procure and current maintenance staff training levels. In addition, the heavy-duty hybrid technology used in the current buses is no longer available and there are no other known providers at this time. This measure is therefore not favored for implementation.

  A new zero emission and super low emission bus procurement will help to identify alternative technologies appropriate for use in Metro's bus fleet.
- **Key Uncertainties**—The efficiency of GHE buses is expected to improve over time while CNG buses are expected to remain at roughly their current efficiency. This change will improve the cost-effectiveness of this strategy. Metro may need to change some of its fueling infrastructure to service these buses if they are put into more widespread use.

  Fuel prices are an important component of this strategy's cost effectiveness. Should a larger fleet of GHEs be employed, Metro may be able to negotiate a more favorable price for gasoline purchases, as it has done with its CNG supply.

  Any decision to invest in gasoline buses over CNG buses should consider impacts on criteria pollutant emission and toxic air contaminants, given the significant air quality problems in Los Angeles County.

  Given the substantial investment that Metro has made in CNG buses, including fueling and maintenance infrastructure, CNG-electric hybrid buses may be a better option for Metro in the longer term. However, there is currently limited information available on CNG hybrid buses because they are not in widespread use at this time.
- **Related Plans**—Metro's Alternative Fuel Initiative directs the agency to only purchase buses that use alternative fuels and supports pursuing state-of-the-art alternative fuel buses.
- **Action Steps**
  - Continue to operate GHE buses on a pilot basis and pursue procurement of zero emission and super low emission buses in the near future.
  - Monitor the experiences of other transit systems operating GHE and other zero and low emission buses to identify operational and technology changes that would benefit Metro's pilot fleet.

- – Evaluate the potential for CNG-electric hybrid buses as the technology advances. Consider serving as a pilot site for testing these buses. Additional study will be needed before pursuing these buses.

Biomethane in CNG Buses

- **Implementation Status**—Metro has made preliminary investigations into the purchase of biomethane, but has decided not to pursue it at this time due to cost factors and other reasons.
- **Barriers to Implementation (other than costs)**— California law currently prohibits the injection of methane captured from landfills in California (AB 4037, Statutes of 1988) into utility pipelines. Therefore, to procure biomethane, Metro would have to pay its natural gas provider to source biomethane from outside of California. Otherwise, Metro would have to procure biomethane directly from a landfill capture system (or a dairy digester, depending on volume requirements and availability) and have the natural gas delivered directly to Metro facilities. The direct delivery will likely be more expensive for Metro for two reasons. Firstly, biomethane is likely more expensive than conventional natural gas. Secondly, direct delivery will likely occur via truck, which is far less cost effective than transmission via pipeline. Delivery via pipeline could require the construction of a parallel biomethane network, which would have a substantial cost associated with it. Regardless of the source of its natural gas, the fuel compressed on-site for use in Metro's transit buses would be indistinguishable as "conventional" natural gas or biomethane.

  Metro has had discussions with their utility about biomethane, but there have been problems with the credit system used to purchase biomethane.

  As an alternative to using biomethane that has been refined to be indistinguishable from regular natural gas, there is the potential that Metro could use raw biomethane if modifications are made to the buses. This option has not been explored in depth.

- **Key Uncertainties**—The potential for biomethane production in California may constrain the implementation of this strategy. However, a report prepared for the Western United Dairymen estimated that the technical resource potential of California's biomass waste streams is about 23 billion cubic feet (BCF) annually, or about 170 million diesel gallon equivalents.[7] Biomethane captured from landfills has a technical potential around an additional 60 BCF/yr, expected to increase to nearly 80 BCF/yr by 2020.[8] For the sake of comparison, Metro consumed approximately 5.4 BCF of CNG in 2010. There is therefore sufficient local feedstock to supply Metro with biomethane, although there is not currently adequate infrastructure for production and transportation of biomethane.

  Biomethane is likely to come at a price premium versus conventional natural gas, but the costs for biomethane are unknown. There may also need to be incentives in place to ensure some biomethane use in the transportation sector instead of the power generation sector.

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[7] Krich, K *et al*. July 2005. "Biomethane from Dairy Waste: A Sourcebook for the Production and Use of Renewable Natural Gas in California."

[8] Williams, RB. March 2007. *Biofuels from Municipal Wastes—Background Discussion Paper*.

- **Related Plans**—Metro's Alternative Fuel Initiative directs the agency to only purchase buses that use alternative fuels and supports pursuing state-of-the-art alternative fuel buses.
- **Action Steps**
  - Monitor biomethane production levels, particularly for technological breakthroughs that bring more biomethane to the market.
  - Work with utilities to identify opportunities to source biomethane cost-effectively for Metro, including through the use of tax credits or other incentives that may be available.
  - Research options for distribution of biomethane and where refining activities should occur. Work with utilities to refine and potentially implement resulting proposals.

Facility Lighting Upgrades

- **Implementation Status—**Metro stated in early 2012 that only about 20% of potential lighting retrofits had been completed to date, almost all of them linear fluorescents, across all Divisions. Thus, Metro is still using T12 lamps and older metal halides in many fixtures. Beginning in July 2012, many T12 lamps will be phased out of production, and compatible ballasts have already become scarce, so Metro will likely be forced to replace all T12 lamps shortly.
- **Barriers to Implementation (other than costs)**
  - More education is needed among relevant staff and decision-makers regarding the appropriate technologies. For example, T-5 lamps or LEDs were suggested by Metro staff instead of T-8s because they tend to be lower wattage, but neither T-5 lamps nor LEDs are a good strategy to apply portfolio-wide because—cost differences aside—they are designed for highly specialized fixtures such as accent lighting for architectural features and have lower light output for the amount of energy consumed.
- **Key Uncertainties**
  - Lighting audits have only been conducted at Divisions 10 and 18. Potential retrofits at other Divisions may be different.
- **Related Plans—**Metro's Energy Conservation and Management Plan, adopted 2011.
- **Action Steps**
  - Explore complementary strategies such as delamping, daylight harvesting, and occupancy sensors. Lighting retrofits should occur simultaneously with other lighting best practices, such as delamping where conditions are over lit, not only for practical purposes, but also because greater savings are realized when these strategies are used in tandem.
  - Conduct lighting audits of Divisions other than 10 and 18 to establish baseline and document savings.

Expand Use of Renewable Energy

- **Implementation Status**—Metro has already deployed and is using 2.1 megawatts of electricity from renewable energy sources, solar photovoltaics (PVs) in particular, fulfilling about 2% of the Agency's energy needs. The largest of these installations is 1 megawatt of solar PV and is located at the Central Maintenance Facility. Additional pilot or demonstration projects are planned or underway at four locations:
  - *Wind tunnel energy—Red subway line.* Planned but not begun.
  - *Solar PVs—El Monte Station on Silver line.* Almost complete
  - *Large scale renewable energy project—Transit facilities.* Technologies being selected, but no project begun.
  - *Solar PVs—Pico Station on Blue line and possibly others.* Not yet begun.
- **Barriers to Implementation (other than costs)**
  - Infrastructure challenges, such as Metro's changing building portfolio. For example the Pico Station will need to be rebuilt because of a new stadium, so it is unclear if the solar PV panels should be installed now or at a later date.
  - Metro must find publicly acceptable sites with access to transmission lines and good resource profiles (i.e., plenty of sun or wind). For example, prospective wind sites may require several years of monitoring to determine whether they are suitable.
  - Unlike conventional energy projects where permitting requirements are well defined and understood, permitting for renewable energy projects involves a different set of issues and new regulations with which Metro staff may be unfamiliar.
  - Addressing issues raised by internal and external stakeholders who may be unfamiliar with renewable energy technologies.
  - Certain assets on which projects could be installed are not owned by Metro, and would require third party involvement.
  - Market barriers such as inadequate information, lack of access to capital, "split incentives" between building owners and tenants, and high transaction costs for making small purchases
- **Key Uncertainties**—Primarily local constraints that include:
  - Decreasing availability and amount of energy rebates;
  - Lack of control over unit costs of energy;
  - Fast evolving renewable technology advances that may create operations and maintenance challenges if deployment of existing technologies is carried out significantly ahead of more cost-effective ones
- **Related Plans**—Metro's Renewable Energy Policy, adopted 9/14/11. Metro's Energy Conservation and Management Plan, adopted 2011.
- **Action Steps**

- Analyze the potential cost and energy impacts of this strategy in greater detail, including analyses for individual facilities as directed by the Board in February 2011.
- Compare this strategy to other strategies that reduce energy consumption from the grid, such as energy efficiency programs, both separately and in conjunction with this strategy.
- Consider a broad range of technology options and deal structures, i.e. onsite, offsite, leased, PPA, owned, etc.
- Consider piloting renewable technologies in rail yards.
- Consider installing monitoring equipment to document actual energy production and savings.

Retrofit Lighting in Red Line Tunnel

- **Implementation Status**—This project has now been approved by the Metro Board and implementation is expected to begin this year. Metro has selected an LED lighting technology to be used in the Red Line Tunnel. The expected lifetime of the lighting is 10 years—even longer than the 4 years assumed in the analyses above.
- **Barriers to Implementation (other than costs)**—None. The project is being implemented.
- **Key Uncertainties**—Beyond the energy consumed by the light fixtures, Metro will be able to reduce its maintenance activities associated with changing light fixtures in the tunnel. Metro predicts that they will be able to substantially reduce the amount of labor and vehicle travel and idling, increasing the strategy's emission reductions and contributing to its cost-effectiveness. Labor costs and vehicle emission reductions will need to be verified once the strategy is in place.
- **Related Plans**—Metro's Energy Conservation and Management Plan is a strategic blueprint intended to guide Metro's energy use in future years. While the Red Line Tunnel lighting retrofit is not directly addressed in that plan, the plan's approach to energy management applies to tunnel lighting, particularly for any future changes.
- **Action Steps**
  - Monitor the costs and energy usage associated with the new lighting to ensure the project meets expectations and to identify additional areas for cost and energy saving.
  - Investigate opportunities for operational changes in the servicing of the tunnel that could contribute to lower costs and emissions.
  - Evaluate new technologies every 4 to 5 years as the new fixtures reach the end of their life and need to be replaced.

Municipal Recycled Water for Bus Washing

- **Implementation Status**—Recycled water systems are operational at Division 3 and close to operational at Divisions 18 and 15.
- **Barriers to Implementation (other than costs)**—The availability and quality of recycled water will vary from division to division. Metro has experienced issues with recycled water at

some of the divisions that have access to it. The quality of the water at some facilities is not sufficient for bus washing. These facilities are still using potable water for bus washing.

- **Key Uncertainties**—The impact of this strategy will be reduced if municipal recycled water is not available at all Divisions, as was assumed in the analysis. Addressing the current operational issues may also increase the cost of this strategy.
- **Related Plans**—Metro's Water Action Plan provides an analysis of the potential water and energy savings and cost impacts associated with this strategy.
- **Action Steps**
  - Fine-tune this strategy through the pilot sites and then develop a plan for Metro-wide deployment based on those experiences. Address current operational issues before deploying to more divisions.
  - Use of recycled water at Metro facilities should be considered on a site specific basis considering the quality of the available recycled water and the retrofit requirements to modify existing plumbing, consistent with applicable state requirements. Metro has begun to do this through an analysis of recycled water availability at each division.
  - Additional training for staff running the bus washers and general education about recycled water will improve strategy effectiveness and ensure there is no improper use of the recycled water.

Extension of Bus Wash On-Site Water Reclamation

- **Implementation Status**—This strategy has not been implemented. However, an alternative strategy that would achieve the same goal of increasing the amount of water reclaimed is currently being explored at Metro. That strategy involves the use of more efficient air blowers.
- **Barriers to Implementation (other than costs)**—There are currently operational challenges to reclaiming water used in bus washing. To capture as much run-off as possible, buses must adhere to a 2 miles per hour speed limit through the washers, and air blowers should be activated to enhance run-off while the bus is over the grates. The Water Action Plan notes that during data logging, it was observed that the air blowers were not consistently operated. Similarly, the speed restriction is not strictly enforced.
- **Key Uncertainties**—The bus washing schedule complicates efforts to address operational issues because buses typically come through the washers in large groups. If the operational issues cannot be addressed, this strategy will be less effective than it otherwise would be.
- **Related Plans**—Metro's Water Action Plan provides an analysis of the potential water and energy savings and cost impacts associated with this strategy.
- **Action Steps**
  - Evaluate the potential for every-other-day bus washing and assess what combination of strategies (operational and floor grates) would most effectively increase water savings.
  - Consider incorporating improved air blowers as part of this strategy.

- Identify pilot sites at which to test the strategy.
- Fine-tune this strategy through the pilot sites and then develop a plan for Metro-wide deployment based on those experiences. Address current operational issues before deploying to more divisions.
- Additional training for staff running the bus washers may help address operational issues and will improve strategy effectiveness.
- Consider washing each bus every other day instead of every day. This would halve bus washing water consumption, and potentially make it easier to adhere to the operational procedures for maximum reclamation. This strategy could be implemented separately or jointly with the floor grate extension.

Low Water Sanitary Fixtures

- **Implementation Status**—Metro has installed low water sanitary fixtures in its headquarters facility.
- **Barriers to Implementation (other than costs)**—Low water urinals in Metro's headquarters facility have caused calcification of copper pipes. The pipes around those urinals have had to be replaced in order to keep the urinals working.
- **Key Uncertainties**—The need to replace pipes around low water urinals have greatly increased the costs associated with this strategy. If this is a widespread issue and no easy remedy is found, the cost-effectiveness of this strategy will be reduced and Metro may curtail the installation of these fixtures.

  The effectiveness of this strategy depends in part on staff education, particularly around the use of dual flush toilets. Without some behavior change, this strategy may not achieve the savings projected.
- **Related Plans**—Metro's Water Action Plan provides an analysis of the potential water and energy savings and cost impacts associated with this strategy.
- **Action Steps**
  - Monitor low water fixtures that have already been installed at a few sites. Fine-tune this strategy, and then develop a plan for Metro-wide deployment.
  - Identify solutions for the issue with copper pipes and low water urinals before continuing to expand this strategy to other facilities.
  - This strategy focuses on fixtures installed prior to 1992. Once those are replaced, start looking at more recent fixtures and replace them over time as more efficient technologies become available.
  - Education and outreach will reinforce the water savings the sanitary fixtures are designed to provide. Education of staff is important to ensure they understand how some low water sanitary fixtures work, such as dual flush toilets.

3. Adapting to the Effects of Climate Change

3.1. Background/Study Design

The adaptation study represents a high-level screen, designed to identify some of the most important Metro services and assets that are likely to be affected by climate impacts. The first step of the study was to identify the "critical" assets and services within the Metro system. Then, through examination of local historical climate data and projections for future climate conditions, the vulnerability of these critical services and assets was assessed qualitatively. Finally, several potential adaptation strategies were identified that could address these vulnerabilities.

It is important to keep in mind that the adaptation study was performed with several limiting constraints:

- Only public transit services and assets owned and operated by Metro were assessed, in order to focus on adaptation decisions that Metro might pursue (as opposed to decisions that would fall under the jurisdiction of city, state, or federal transportation agencies). As a result, some types of infrastructure upon which Metro services rely (such as city roads or freeways), were not directly assessed.
- The adaptation study primarily focuses on system-level and line-level vulnerabilities and potential adaptation measures.[9] This high-level analysis was intended to guide future work that might be performed at a higher level of resolution, and could provide information about individual assets or facilities.
- The adaptation options presented should not be considered recommendations. These options have been selected from relevant literature and the experience of other transit agencies pursuing adaptation. Metro's decision to pursue any of these options would likely require further consideration of overall management goals as well as the costs and benefits associated with a particular option.

3.2. Characterizing Critical Services and Assets

The first step in developing a climate adaptation strategy is to identify Metro's "critical" services and assets.

Why a Criticality Assessment?

The universe of transportation services and assets in Los Angeles County is extensive. Compiling an inventory of these services and assets would be an arduous task, and attempting to analyze the potential climate impacts on all of these services and assets would be difficult. The criticality analysis is an important part of the screening nature of the overall adaptation study - it focuses Metro's first attempt at a climate change adaptation strategy on the parts of its system that are most important to the reliable provision of transportation. Essentially, these

[9] Criticality scores were generated for individual rail and some large bus stations. Although vulnerability for these individual facilities was not assessed, these criticality scores could be used to direct future investigations of vulnerability. See section 3.2 for more details.

services and assets can be thought of as the "keystones" of the current and future ability of Metro to serve its transit customers.

How Has Criticality Been Defined for Metro?

The definition of "critical" is dependent on context. For example, the Department of Homeland Security's list of critical infrastructure is generated with respect to security and safety threats. In contrast, a list of critical infrastructure or critical assets for a transportation network might focus more on ridership, traffic patterns, and various modes of transportation. What is critical for a particular management goal may not be considered critical when pursuing another management goal.

For this analysis, "criticality" has been determined in a simple and qualitative manner: "**critical" services and assets are those that are essential to transporting Metro's customers**. Essentially, we ask the question, "*If this service or asset were removed from the transit system, would the transit system be fundamentally different*?" A critical service or asset would be extremely difficult or costly to replace or to substitute.

Results of the Criticality Analysis

Existing Critical Services and Asset Types

We identified several critical services and asset types, shown in Table 8. The classification of criticality is explained in the "Rationale" column, and is usually based on the ridership or investment associated with the service or asset.

Table 8: Critical Services and Asset Types

Service or Asset Type	Rationale for "Criticality"	What Does This Include or Exclude?
Bus		
Bus Fleet	Over 1 million weekday boardings; FY10 budget is over $300 million; 2009 *LRTP** projects costs to be over $10 billion for the 2005-2040 period	Includes: Existing bus fleet; Expected capital costs for new buses Excludes: Roads; Stop locations; Fleet has not disaggregated by routes or bus-type (e.g., length/size)
Bus Rapid Transit Service (Silver and Orange Lines)	Over 200,000 weekday passenger miles (representing over 6% of all bus passenger miles)	Includes: Right-of-way
Rail		
Heavy Rail (Red and Purple Lines)	Over 140,000 daily boardings; Most frequented subway lines; Service to much of Downtown Los Angeles	Includes: Location of track, stations, power supply and distribution
Light Rail (Blue, Green, and Gold Lines)	Broad geographic range across the county; approximately 150,000 daily boardings	Includes: Location of track, stations, power supply and distribution
Rail Rehabilitation	FY10 budget is over $30 million; *LRTP* lists costs to be over $9 billion for the 2005-2040 period	Includes: Upkeep costs for maintaining rails
Rail Fleet	FY10 and FY11 budgets are over $50 million	Includes: Existing rail car fleet; Expected capital costs for new rail cars

**LRTP corresponds to Metro's 2009 Long Range Transportation Plan*

Since the services and asset types listed in Table 8 represent broad sets of infrastructure, vehicles, and activities, explanations of what is to be included and excluded are shown in the subsequent, rightmost columns. Further discussion is provided below:

- **Bus Services:** Since Metro does not own and operate the roads where Local, Rapid, and Express lines are operated, the roads are excluded from the analysis. Also, since no single bus line accounts for more than 3% of total bus ridership, individual lines and individual buses (or bus-types, e.g., 40-foot versus 60-foot buses) are not considered, with the exception of the Bus Rapid Transit (BRT). The Orange and Silver BRT lines were considered separately from other bus services since:
  - The ridership is higher than most other bus lines.
  - The length of average passenger trips on these lines is greater than most other bus lines (which is reflected in the relatively large value of total passenger miles).
  - The BRT right-of-way (ROW) is distinct from and more difficult to relocate than a route for typical bus service. Unlike typical bus routes, the ROWs for the BRT lines are included in the set of critical assets.
  - The establishment of more permanent stations, the presence of joint development real-estate projects, and plans for expansion represent a significant investment on the part of Metro, above and beyond what is associated with other non-BRT bus lines.
- **Rail Services:** All the heavy and light rail lines have been included, with special attention to the rail fleet, passenger stations, tracks, and power supply. Rail rehabilitation activities have also been included due to the relatively large amount of resources devoted to them, as described in the 2009 *Long Range Transportation Plan*.

In further recognition of the broad nature of the critical services and asset types in Table 8, specific locations owned and operated by Metro were analyzed for criticality. These locations represent the places where critical services are offered (e.g., passenger stations) or where critical assets are maintained (e.g., rail or bus yards). The full list of approximately 175 locations that were analyzed is shown in the Appendix (Section 5.4). For each of these locations, the following data was collected, if available:

- **Ridership**—Do a relatively large number of passengers utilize this location to access Metro services?
- **Connectivity—**Is this location connected to many other parts of the transit network?
- **Joint Development**—Has a joint development project been planned or completed at this location?
- **Expert Opinion—**For many of the non-passenger facilities, it was difficult to obtain the above data, or such data is not applicable. In these cases, expert judgment from officials at Metro was used to determine the criticality of a location.

As mentioned previously, although criticality was assessed for these facilities, the subsequent discussion of impacts, vulnerability, and adaptation options does not address the individual locations. However, it is possible that future work on impacts, vulnerability, and adaptation might focus on some of these critical locations.

Table 9: Critical Facilities or Locations

Facilities— Passenger Stations	Estimated Rail Daily Weekday Ridership*	Connections to Other Lines**	Joint Development	Criticality Index
7th /Metro Center (Red, Purple, Blue, Silver)	39,000	50	Completed	7
Union Station (Red, Purple, Gold)	30,000	36+Parking	Completed	7
Imperial/Wilmington (Blue, Green)	18,000	10+Parking		6
North Hollywood (Red, Orange)	16,000	12+Parking	Under negotiation	7
Wilshire/Vermont (Red, Purple)	13,000	5	Completed	6
Pershing Square (Red, Purple, Silver)	11,000	50		6
Westlake (Red, Purple)	9,000	15	Under construction	7
Hollywood/Highland (Red)	8,000	2+Parking	Completed	6
Universal City (Red)	8,000	2 + Parking	Under negotiation	6
Civic Center (Red, Purple, Silver)	5,000	50		6
Hollywood/Vine (Red)	5,000	2+Parking	Completed	6

Facilities— Non-Passenger Properties	Rationale
Division 13— Bus Maintenance Facility	Main bus maintenance facility; Co-located/adjacent to Location 30 (Metro Support Services Center), Location 99, Location 33 (OCI), Location 35 (Facilities Maintenance), Location 88 (Westside-Central Service Sector
Location 61— Red Line Maintenance of Way	Important rail maintenance location
Location 66— Blue Line Maintenance of Way	Important rail maintenance location
Location 99— Gateway Building	Metro Headquarters, Adjacent to Union Stations

* *Rounded to the nearest thousand. Calculated as the sum of daily boardings and alightings, divided by 2. Only includes rail statistics—for stations that list the Orange and Silver Lines, the ridership from those BRTs has not been included.*

To assess the criticality of the locations, a criticality index was created. The index has a maximum score of 7, representing a location with relatively high ridership, a high level of connectivity to other transit lines and/or a dedicated parking lot, and the presence of a joint development project. Stations receiving a score of 6 or 7 were considered to be critical.

For the ridership and connectivity data, sub-scores between 1 and 3 were assigned to each station, as shown in Table 10. If a station had a joint development project (either planned or completed), it would receive a sub-score of 1; if it did not have a joint development project, then it received a sub-score of 0. The three sub-scores were added together to calculate the criticality index.

Table 10: Criticality Index Sub-Scores

Ridership	Connectivity	Score
Greater than or equal to 5,000 daily riders	Connected to 10 or more other transit lines	3
1,000-4,999 daily riders	Connected to 5-9 lines, *or* Has dedicated parking spaces/park-and-ride lot	2
Less than 1,000 daily riders	Less than 5 connections and no parking	1

The ridership data was limited to rail stations (bus ridership was available for each bus line, but was not disaggregated by stations or terminals). The ridership values represent the sum of the boardings and alightings occurring at a particular station, divided by two. The data were taken for FY2010 (July 2009–June 2010).

Connectivity represents the sum of other transit lines that can be accessed from a particular station. This includes other Metro rail lines, bus lines, Amtrak train service, other bus transit providers (e.g., Santa Monica Transit buses), and Metrolink. The full connectivity scoring is shown in the Appendix (Section 5.4).

It was more difficult to collect data about the facilities that are not directly associated with passenger services. We relied on expert judgment from Metro to examine our list and determine which of the non-passenger facilities were critical. These are shown in the last 4 rows of Table 9.

Although information on the size (in square feet) of real estate parcels was provided by Metro, a method for using this information to determine criticality was not developed. It was not clear that size alone was a good indicator of the importance of a particular facility.

Anticipated Future Services and Assets

In addition to Metro's existing services and assets, we have included the transit projects that are planned for construction using Measure R funds. Although many aspects of these projects have yet to be determined (e.g., decisions about locations and modes have not always been made), these services and assets are included in a similar fashion to those listed in Table 8; i.e., the vulnerability assessment will consider each of these projects holistically; impacts on each piece of equipment or segment of the line will not be considered.

For all of these projects, the rationale for treating them as "critical" stems from Metro's sizeable planned investment (see the "Expected Cost" column) for each of them. The years listed correspond to the 2009 *Long Range Transportation Plan*; should the 30/10 Plan be approved and implemented, many of these start years would be advanced significantly.

Table 11: Future Services and Assets

Projects	Mode	Expected Cost (in millions $)	Year
Exposition Line	Light Rail	862; 1450	2011; 2015
Orange Line Extension (Canoga Extension)	Bus Rapid Transit	221	2013
Wilshire BRT	Bus Rapid Transit	124	2015
Gold Line Extensions	Light Rail	851;2490	2017; 2035
San Fernando Valley East North-South Rapidways	Bus	170	2018
Crenshaw/LAX Corridor	Light Rail	1715	2018
Regional Connector	Light Rail	1073	2019
Purple Line Extensions	Heavy Rail	1950;2450;1615	2019; 2026; 2036
West Santa Ana Branch Right-of-Way	TBD	649	2027
Green Line Extensions	Light Rail	330;555	2028; 2035
San Fernando Valley I-405 Corridor	TBD	2,468	2039

**Multiple listings for costs and years correspond to projects that are planned in sequential phases.*

3.3. Identifying Impacts of Climate Variability and Climate Change on Metro's Assets and Services

Synopsis

This section of the Plan summarizes the best available historical data and future projections regarding temperature, precipitation, and sea level rise for the Los Angeles County area.

Major findings about observed and future climate conditions include the following:

- Temperature in the region has increased by about 2°F, based on a comparison of the last 30 years with earlier decades of station data in Los Angeles County. Incidents of warm daily temperatures have occurred at a disproportionately higher frequency during the recent 30-year period. All model projections show warming for the future and an increase in the frequency of extremely hot days. Some of the models show exceptionally large amounts of warming (in excess of 10°F) for seasonally averaged summer temperature.
- Seasonal precipitation has not changed much during the last century; however, there is strong year-to-year variability in precipitation, which is expected to persist in the future. There is some evidence of an increase in the frequency of events of heavy precipitation within the station data; however, it is unclear if such a trend might continue into the future based on model simulations. Regardless, the region has experienced events of heavy rainfall in the past and will continue to experience such events in the future.
- Sea level has risen along the California coast during the 20th century. The rate of sea level rise has been accelerating, and is expected to continue to accelerate. Projections for the mid-21st century correspond to a sea level rise of about 1 foot; for the end of the 21st century, projections range from about 20 inches to approximately 5 feet of sea level rise.

Research of the relevant literature (TRB, 2008; FHWA, 2010; NRC, 2010) and discussions with Metro staff indicated that **the most important impacts on Metro's services and assets in the coming decades stem from periods of extreme heat and episodes of heavy precipitation.**

This focus on extreme heat and precipitation events is consistent with how weather and climate typically affect infrastructure, and more broadly "the built environment." Most infrastructure is subject to design standards that are often tailored to regional or national weather and climate conditions. Thus, small changes in the average temperature or precipitation are unlikely to affect the performance and functionality of infrastructure. Issues with services and assets arise in the "tail" of the distribution of temperature and precipitation—the extreme events—when the "normal" conditions are exceeded. The recommendations in this memorandum are aimed to help Metro gauge its resilience to extreme temperature and precipitation events, and to take steps to bolster its resilience.

We also examined sea level rise; however, nearly all of Metro's current services and assets are not located in low-lying areas near the coast, nor are they near floodplains that might be affected by sea level rise. The low risk of impacts presented by rising sea levels is discussed in below, and a map of the change in the County's floodplains is attached.

Observed Changes in Temperature and Precipitation

Data Sources

We examined two sources of historical temperature and precipitation data:

- Daily temperature and precipitation data for the Pasadena Cooperative Weather Station (COOP Identification 046719), which is the only site in Los Angeles County that is part of the U.S. Historical Climate Network (USHCN).[10] The USHCN has been developed by NOAA's National Climate Data Center "to assist in the detection of regional climate change"; technical details for the procedures for quality control/quality assurance of the data can be found in Karl et al. (1990) and later updates (e.g., Easterling et al., 1999).
- Monthly temperature and precipitation data for California Climate Division 6 (South Coast Drainage).[11]

Both sources extend back in time over 100 years, providing a long-term view of the climate in Los Angeles County. The Pasadena station record is depicted in the figures that follow, and is particularly valuable because it contains daily data, which are useful for considering the frequency and intensity of extreme events, such as heat waves and storms bringing heavy rainfall. However, the drawback in using a station record is that it only represents the conditions at one geographic location.

Although the conditions in Pasadena are not necessarily identical to those throughout the County (for example, coastal areas are likely cooler during the day), the *changes* observed in Pasadena are likely similar to those experienced in the region. The Divisional data set provides

[10] http://cdiac.ornl.gov/epubs/ndp/ushcn/background.html

[11] http://www.ncdc.noaa.gov/temp-and-precip/us-climate-divisions.php

a supplementary "check" of this assumption, since it is drawn from a geographically broader area, stretching from the Mexican border through Santa Barbara County. Any robust trends or patterns detected in the Pasadena data that is due to changes in regional climate should also be evident in the Divisional data.

Observed Temperature Change and Variability

Figure 6 and Figure 7 show the results of our analysis of daily and seasonal temperature (computed from daily records) for Pasadena.

Figure 6 shows average seasonal temperature for three time periods: the full data record from 1910-2009[12], the recent 30-year period, 1980-2009; and the previous decades, 1910-1979. The data demonstrate that the most recent decades were warmer than the previous decades across all seasons, typically by about 2°F. This is generally consistent with the Divisional data (not graphed), as well as trends for the state of California as a whole (Moser et al., 2009). The transparent bars represent the standard deviation of the seasonal averages—they are generally between 2° and 3°F, and represent the magnitude of the year-to-year variations in seasonal temperature. Confidence in the robustness of the recent warming trend is derived from the fact that the magnitude of the warming is roughly equivalent to the annual variability.

Figure 6: Average Seasonal Temperature Observed in Pasadena (in °F). DJF (December, January, and February); MAM (March, April, May); JJA (June July, August); SON (September, October, November)

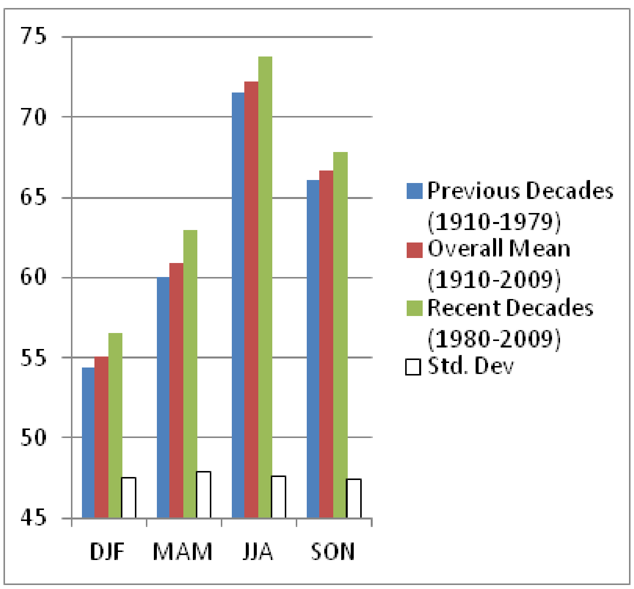


Figure 7: Frequency (in Percentage of Days During a Season) When the 5th Percentile Value (Solid Bars) and the 1st Percentile Values (White, Bordered Bars) for Warm Daily Temperature Are Exceeded

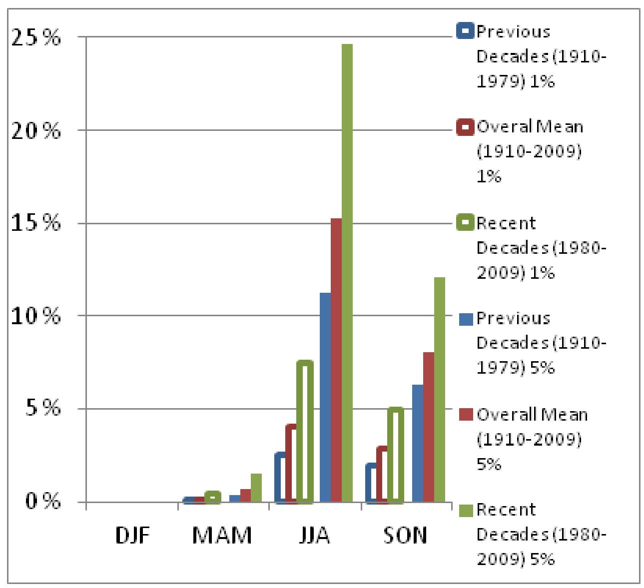


Figure 7 shows the frequency of daily warm extremes. The graph shows the average percentage of days during each season that exceed the 5th and 1st percentile value for daily average temperature for the 1910-2009 period. For the Pasadena station, the 5th and 1st

[12] Prior to 1910, many months lack complete data. Thus, 1910 was considered the start date for our calculations. The data end in December 31, 2009.

percentile values correspond to average temperatures of 79°F and 83°F, respectively. Days with average temperatures (which represents an average of the maximum and minimum temperatures) equal to these values typically have maximum temperatures in the low- to mid-90's°F for the 5th percentile and 100°F (or greater) for the 1st percentile.

Figure 7 demonstrates that warm days have become more frequent during the recent 30 years—the 5th percentile is now exceeded approximately 25% of the time during the summer (JJA) and the 1st percentile is exceeded over 7% of the time. During the decades prior to 1980, the 5th and 1st percentile temperature values were exceeded only about 11% and 3% of the time, respectively.

Although the daily extreme temperature data for the Pasadena station should not be quantitatively extrapolated to the entire Los Angeles County region (i.e., if other stations had such data available with a comparable quality, it is likely that the magnitude of the changes in extreme events would be different), the general conclusion that the incidence of high temperature events has increased is robust and is likely to be true across the County (and the broader region).

Observed Precipitation Change and Variability

Figure 8 and Figure 9 show results for the seasonal averages of precipitation and the daily extremes of precipitation. They are organized in the same fashion as the temperature results.

In Figure 8, there is a slight increase in winter (DJF) precipitation when comparing the recent 30 year-period to the previous decades. However, we do not consider this trend to be significant or robust. The transparent bars demonstrate that the year-to-year variability[13] is extremely large (the standard deviation of winter precipitation is over 7 inches)—the change between the recent decades and previous decades is relatively small compared to the magnitude of the variability. In addition, the Divisional data (not graphed) exhibit a slight drying in its precipitation records. Therefore, we conclude that there are no robust trends in seasonal precipitation. The data (both the station and Divisional sets) do, however, demonstrate an important feature of the hydroclimate in Southern California—the year-to-year variability is relatively large. During the winter, the Pasadena station has experienced anywhere from just over 1 inch of total rainfall, to over 40 inches of total rainfall.

[13] As noted in Cayan et al. (2009) there is also significant decade-to-decade variability in the hydroclimate of Southern California, i.e., the region can also experience one or multiple decades of relatively wet or dry conditions.

Figure 8: Average total Seasonal Rainfall (in Inches).

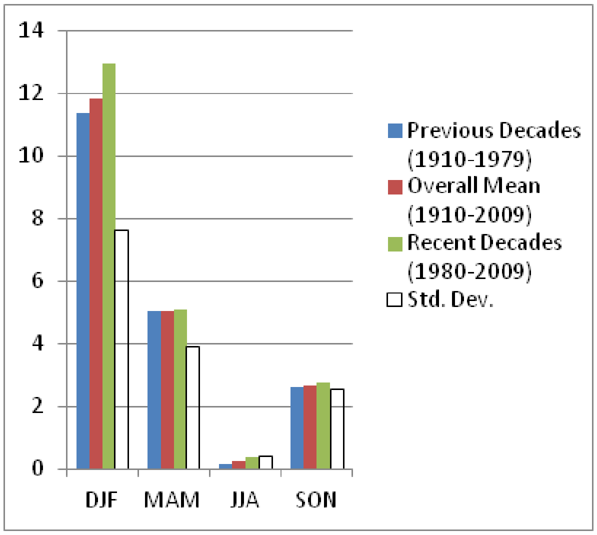


Figure 9: Frequency (in Percentage of Days During a Season) when the 5th Percentile Value (Solid Bars) and the 1st Percentile Values (White, Bordered Bars) for daily Precipitation Are Exceeded

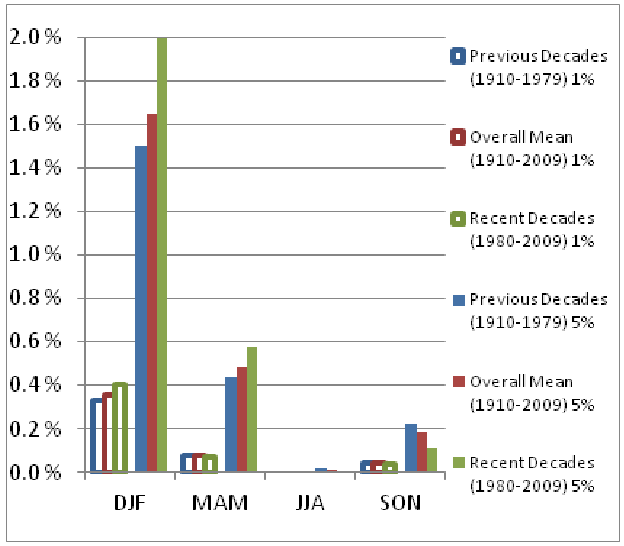


Figure 9 shows the frequency of daily extreme precipitation. The 5th and 1st percentile values for daily precipitation (on days experiencing measureable rainfall) were calculated as approximately 2 inches of rainfall and about 3.7 inches of rainfall, respectively. The graph shows that incidences of heavy precipitation during the winter have become more frequent at Pasadena—the 5th percentile events occur on nearly 2% of all winter days, while in previous decades such events occurred during approximately 1.5% of all winter days. The top-percentile of rain events also exhibited a slight increase in frequency, from just over 0.3% of all winter days during the 1910-1979 period to 0.4% of all winter days in the 1980-2010 period. The changes in the frequency of heavy rainfall events are smaller for the other seasons; during the fall, the recent decades actually exhibit a decrease in the frequency of heavy rainfall events.

It is difficult to assess the quantitative change in the frequency of intense rainfall events based solely on one station's data. A similar analysis for the observational record (Mastrandrea et al., 2009) found no significant trend for Los Angeles County regarding precipitation intensity. However, this analysis used a slightly different metric for intensity (annual precipitation divided by number of rain days), which could bias the results in years with relatively numerous days with light rainfall. On the regional scale, a slight increase in the amount of rainfall during incidences of heavy precipitation has been documented in the Southwest (USGCRP, 2009). Overall, we consider the increase in heavy winter rainfall at Pasadena to be qualitatively consistent with this large-scale picture; for the other seasons, the changes are likely too small to be significant or robust.

Projected Future Temperature and Precipitation

Data Sources

Drawing on work done by the California Climate Change Center, we have collected downscaled model output from 6 global circulation models for the Los Angeles County area. Each model was run using the A2 (relatively greater GHG emissions) and B1 (relatively less GHG emissions) scenarios for the 21st century. For our results, we show the A2 results through the 21st mid-century, and both the A2 and B1 results for the end of the 21st century. This was done because the differences between the A2 and B1 scenarios for temperature are very small prior to the mid-21st century (i.e., the scenario choice does not have a substantial impact on the projections until after 2050).

The six models are as follows: the MIROC 3.2 from Center for Climate System Research of the University of Tokyo, the ECHAM5 from the Max Planck Institute (Germany), the National Center for Atmospheric Research (NCAR) Community Climate System Model (CCSM), the NCAR Parallel Climate Model (PCM), the French Centre National de Recherches Météorologiques (CNRM) model, and the National Oceanic and Atmospheric Administration Geophysical Fluid Dynamics Laboratory (GFDL) model. This subset has been selected from the larger group of available IPCC AR4 models due to their ability to faithfully simulate seasonal temperature and precipitation, the year-to-year variability in precipitation, and the El Niño/Southern Oscillation pattern. The models have been downscaled[14] to the Los Angeles County area. More details about the model output and the downscaling are described in *Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment* (Cayan et al, 2009).

Figure 10 and Figure 11 show the models' simulated average seasonal temperatures and average seasonal precipitation totals for the Los Angeles County region for the "base period" of 1950-1979. These simulations show similar temperatures and precipitation amounts to the values shown in Figure 6 (seasonal temperature at the Pasadena station) and Figure 8 (seasonal precipitation at the Pasadena station). Although there are some differences between the model simulations and the station data (e.g., the station tends to be a bit warmer during the summer and wetter during the winter and spring), their general agreement provides confidence in the fidelity of the models to simulate the seasonal features of the regional climate.

Projected Future Temperature

Figure 12 shows the changes (in °F) in temperature relative to the 1950-1979 base period projected by the six models for the late 20th century (1980-2009), the early 21st century (2010-2039), the mid-21st century (2040-2079), and the late 21st century (2080-2099). The last time

[14] "Downscaling" is the process of modifying the output of a global circulation model, which has a relatively coarse spatial resolution (i.e., the grid points are spaced relatively far apart), to an output with higher spatial resolution. For the California model output, two statistical techniques were applied: bias correction and spatial downscaling (BCSD), and constructed analogues (CA). Since the monthly downscaled data are relatively similar for the two techniques, only the BCSD results are shown in this memorandum. The two techniques do differ at the daily scale. However, the differences are likely to have minimal impact on the interpretation of the output four our analysis since the ability of any of the global models to simulate daily variability is limited, especially for precipitation.

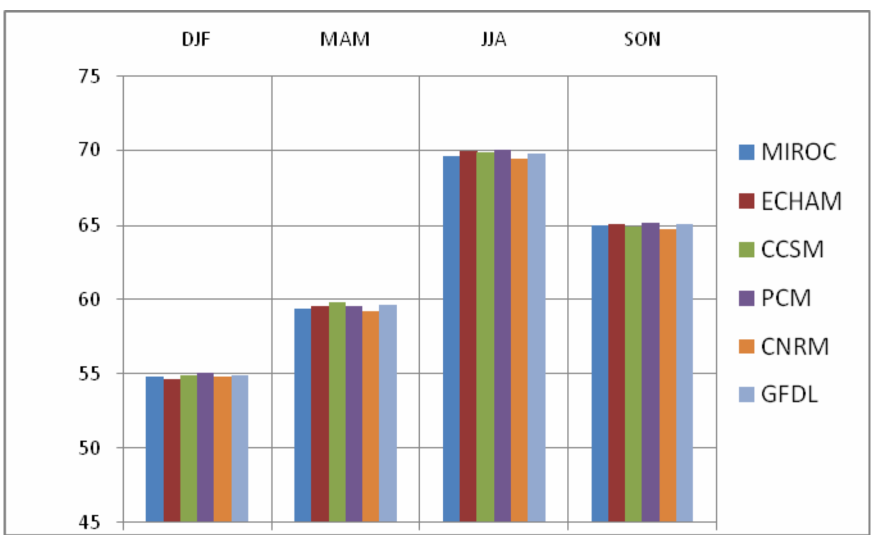
period has two sets of estimates—the higher emissions scenario (A2) and the lower emissions scenario (B1)[15]. Changes for the winter months (DJF) and summer months (JJA) are shown—the models tended to produce the least warming for the winter and the greatest for the summer; the spring and fall projections were typically between the winter and summer.

Although the models show a range of estimates, and the range among the models increases with time through the 21st century, **all the models project increases in temperature**. For mid-century, the increases range between 2° and 5°F for the winter and approximately 3° and 6°F for the summer. For the end of the 21st century, the warming ranges between 3° and 8°F for the winter and 3° and 11°F for the summer.

This amount of warming would be very likely to increase the frequency of extreme heat events that would occur in Los Angeles County, as was shown for the 20th century data in Figure 7. Since the link between increasing temperatures and increases in the frequency and intensity of heat waves is well established, we did not feel it necessary to calculate the increase in the frequency of days experiencing high temperature for the model data, so we have not tabulated a plot analogous to Figure 7 for the models. Similar such analyses have already been performed. For example, using the same model data that we've summarized here, Cayan et al. (2009) have shown that many of the population centers in California would experience more frequent, more intense, and longer-duration heat waves as a result of warming,. In some cases, the frequencies of the long events (greater than 5 days) increase by a factor of 20 by the end of the 20th century (Cayan et al., 2009).

Figure 10: Seasonal temperature for the Mid-20th Century Simulated by Six Climate Models and Downscaled for the Los Angeles County Area

The models are capable of reproducing the season-to-season variation, and the differences among the models are relatively small. As previously shown, DJF (December, January, and February); MAM (March, April, May); JJA (June July, August); SON (September, October, November).



[15] It should be noted that the trajectory of recent global greenhouse emissions (since 2000) has exceeded the trajectory for both scenarios.

Figure 11: Seasonal Precipitation for the Mid-20th Century Simulated by Six Climate Models and Downscaled for the Los Angeles County Area

The models are capable of reproducing the season-to-season variation, although some models are relatively wetter or drier.

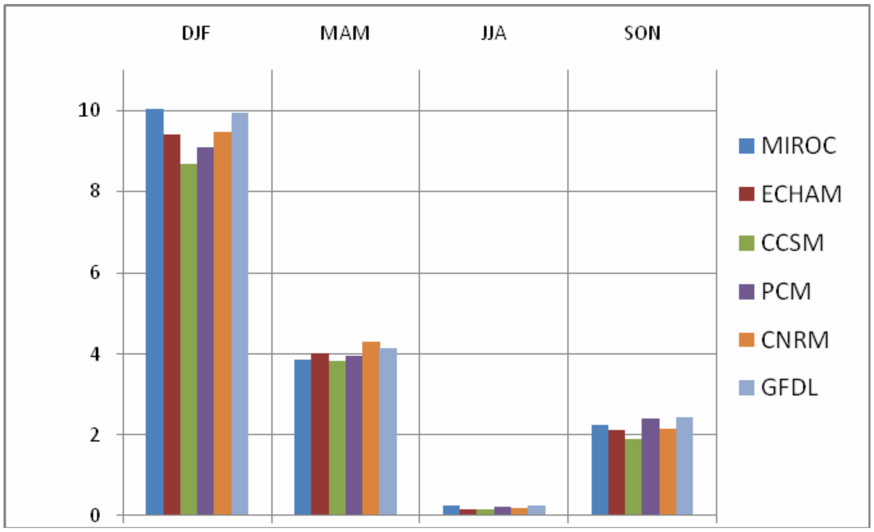
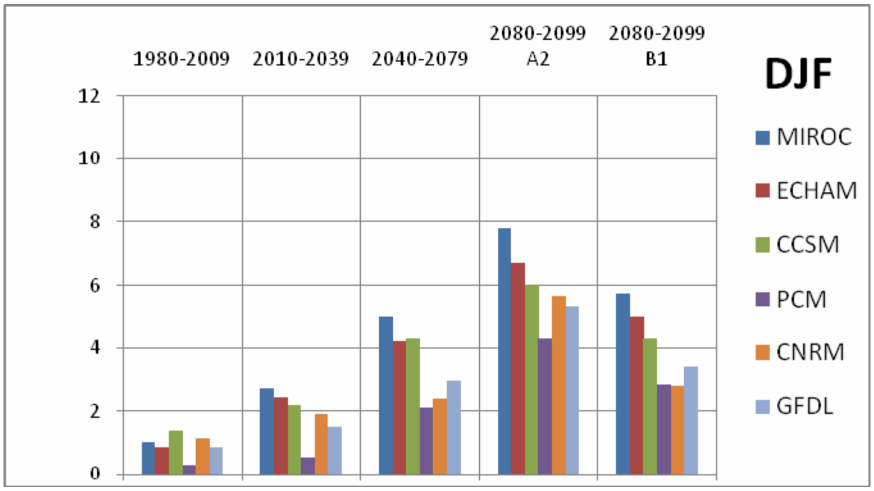
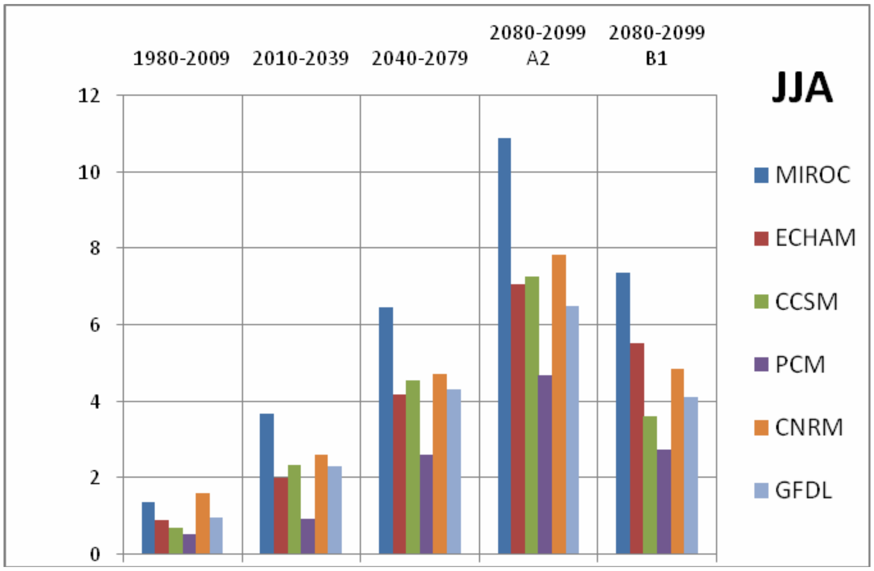


Figure 12: Changes in Late-20th Century and 21st Century Average Seasonal Winter (top, DJF) and Summer (bottom, JJA) Temperature, in Degrees Fahrenheit

Changes are relative to the mid-20th century values shown in Figure 10. Values have been simulated by six climate models and downscaled for the Los Angeles County area. In general, winter is expected to warm less than the other seasons; summer is expected to warm the most.





Projected Future Precipitation

Figure 13 shows the changes (in percent) projected by the six models for average seasonal precipitation totals relative to the 1950-1979 base period; the time periods for the projections are the same as those shown in Figure 12.

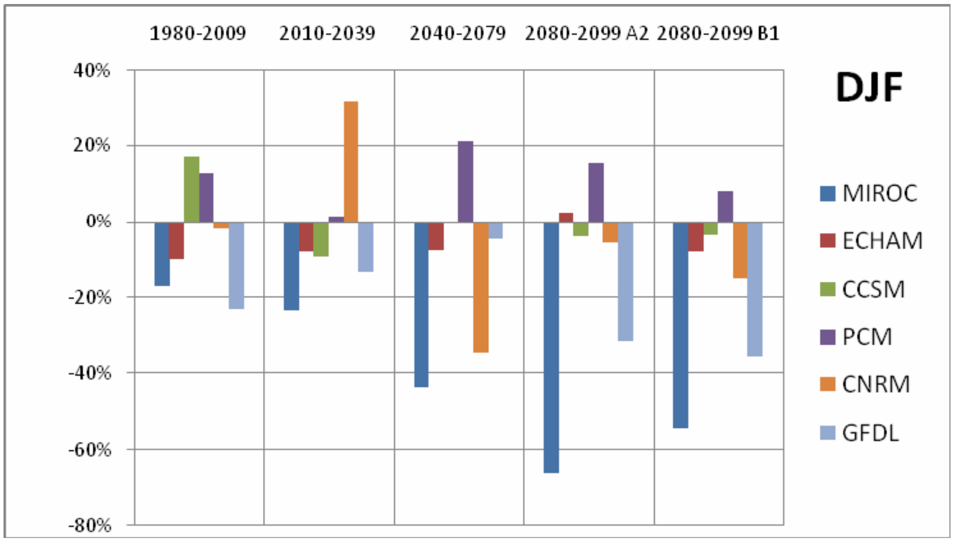
Most models project drier conditions for the winter and spring, with relatively small changes for the fall. Summer is not shown since the amount of summer precipitation, on average, is relatively small. The magnitude of the changes in winter and spring vary greatly, and some models project increases. Surprisingly, some models project inconsistent changes—the CNRM projects a wetter period for the early 21st century, then drier conditions for the later part of the 21st century, potentially indicating that the CNRM has strong decadal variability.

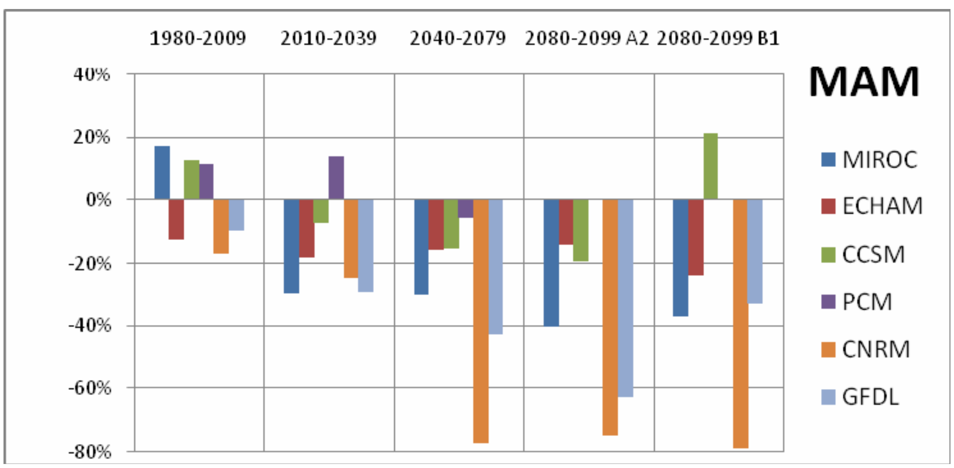
Overall, the models do not provide a robust picture of changes in precipitation. Although some of these models simulate conditions that could represent some drastic changes should they occur and persist (i.e., water planners and ecosystem managers might find it difficult to meet their goals if Southern California were to "lose" 60% of its winter precipitation), corroboration from other models is lacking. Also, the changes, even the ones that are relatively large in magnitude, are still relatively smaller than the year-to-year variability (as measured by the standard deviation in year-to-year winter precipitation, see Figure 8). In other words, many of the projected changes, especially the smaller ones (less than 20% changes in either direction), would be similar to experiencing a slightly wet year or dry year (or wet decade or dry decade) in the current climate.

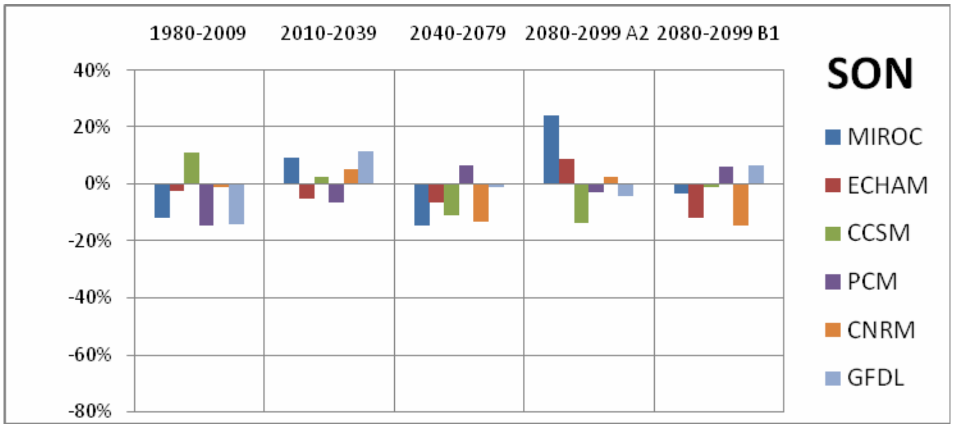
Changes in the nature of heavy rainfall events are somewhat uncertain as well. Daily precipitation extremes represent an area where models are known to perform poorly. Downscaling techniques can also make it difficult to detect changes in such statistics. Using these same model projections, Mastrandrea et al. (2009) show no significant changes in the precipitation intensity for Los Angeles County; as mentioned earlier, there may be issues with their choice of metric that complicate detection of large events. Cayan et al. (2009) show that several of these models show small positive trends in large precipitation events (> 1 inch of rainfall) in the 21st century, but that these trends do not pass the significance test that they apply.

Figure 13: Changes in Late-20th Century and 21st Century Winter (top, DJF), Spring (middle, MAM), and Fall (bottom, SON) Precipitation, in Percent

Changes are relative to the mid-20th century values shown in Figure 11. Values have been simulated by six climate models and downscaled for the Los Angeles County area. The models show tremendous differences in the amount and direction of precipitation changes.







Evidence of Impacts for Extreme Heat Events and Heavy Rainfall

We have collected information about the recent occurrences of extreme heat and heavy rainfall in Southern California. This information has been used to identify a set of operationally-important temperature thresholds and precipitation impact-analogs, presented in Figure 14 and Table 12.

Figure 14: Anecdotal thresholds for heat-related impacts to Metro Bus and Rail Operations

The frequency information is derived from the meteorological records for Pasadena, where available. These events, including the rarely observed events, are likely to become more frequent in the future.

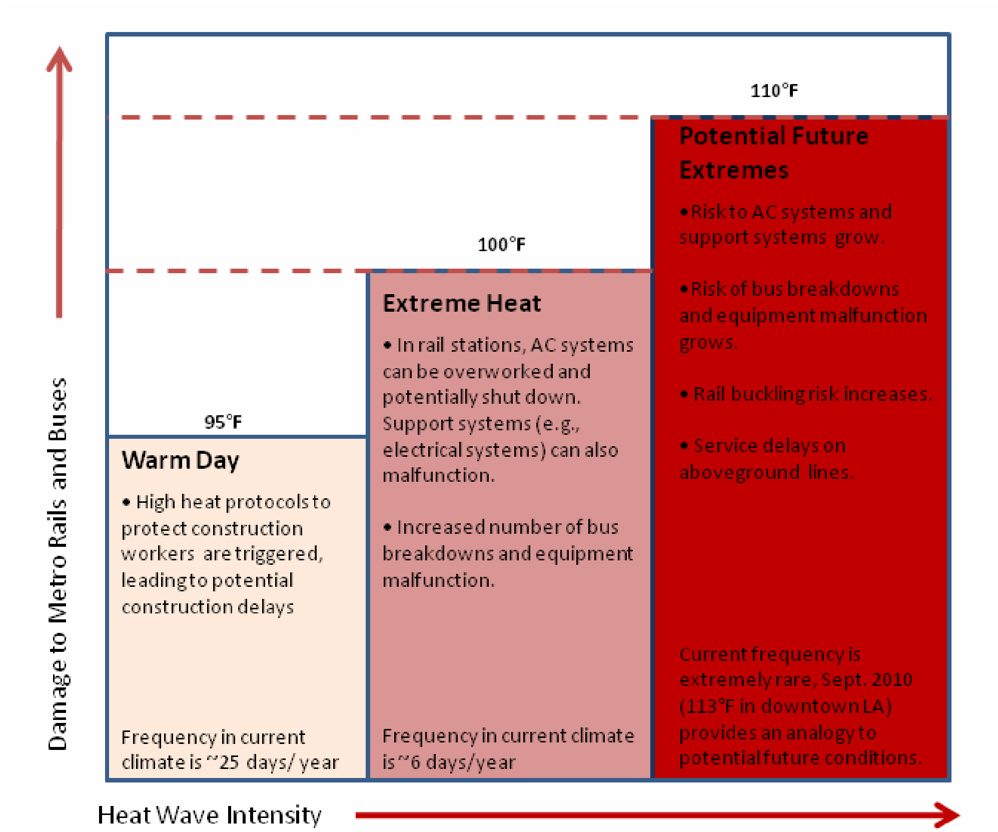


Table 12: Impact-Analogs for Heavy Precipitation Impacts on Regional Transportation

These events included 5 percentile (approximately 2 inches in one day) and 1 percentile (approximately 3.7 inches in one day) extreme precipitation events.

Date	Precipitation	Storm Description	Transportation Impacts
Dec. 30, 2010	LA area: 0.5-1.5" over 12 hours	With the ground already saturated from previous rainfall, strong winds toppled many trees, producing scattered power outages and road blockages.	Significant damage to commuter rail service in L.A. County - power outages, tangled overhead electric lines, and lightning storms. Long delays on Metro's rail service (*LA Times*, 2010)
Feb. 19, 2005	LA area: 4-8" over 2 days; Pasadena: 3.2", over 12" over 5 days	$8-10 million in damages, mostly agricultural. Storm damage throughout entire state may total $500 million. 2 day power outages (*The LA Times*, 2/5/2005)	Numerous roadways were closed (Interstates 5 and 10, Highway 101) due to mudslide and flash flooding.
Jan. 7, 2005	LA area: 3-10" over 5 days; Pasadena: almost 13" over 5 days	$5 million in property damage; flash flooding responsible for 1 fatality in Los Angeles and damage to homes in Santa Clarita.	Road closures, road damage from mudslides (*LA Times*, 1/11/2005 and 1/16/2005) Mudslides and deep water closed five of six Pacific Union rail lines out of the Los Angeles Basin, bringing its rail service to a virtual standstill (*LA Times*, 1/12/2005)

Increasing Precipitation; Increasing Impacts

Sea Level Rise

During the past several decades, the California coast as a whole has experienced a rate of sea level rise of about 7-8 inches (17-20 cm) per century (Cayan et al, 2009; Church and White, 2006). This has been approximately equal to recent rates of global sea level rise. Cayan et al. (2009) have used this relationship, along with the empirical relationship between global surface air temperature and sea level developed by Rahmstorf (2007) and some modifications for the influence of dams and reservoirs on runoff (see Chao et al., 2008) to make estimates of sea level rise for California for the future.

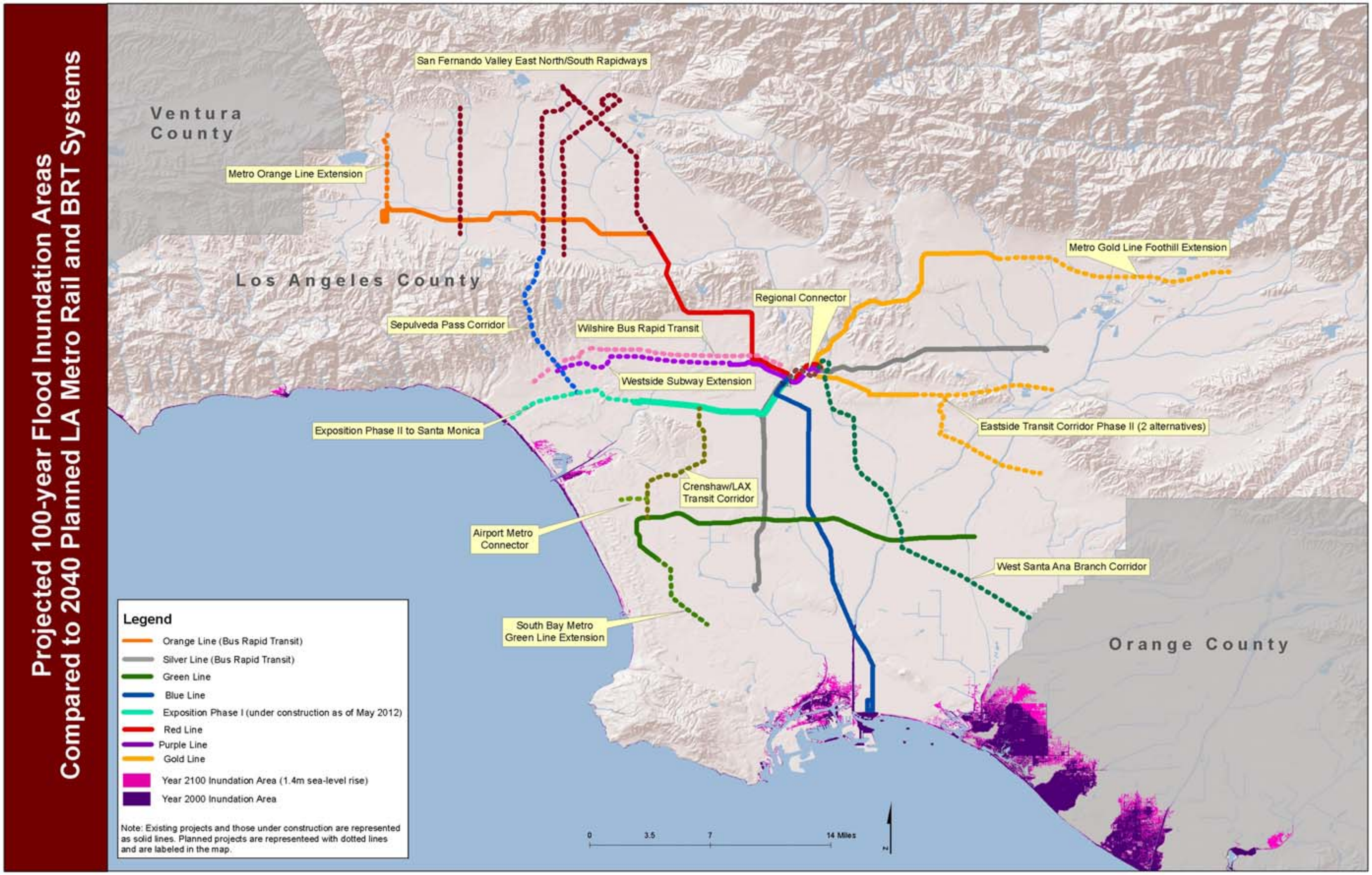
The future rates are projected to accelerate, with 12 to 14 inches (30-45 cm) of additional sea level rise (relative to sea level in 2000) occurring by the mid-21st century. Projections for the end of the century are more dependent on the choice of model and scenario (i.e., projections for larger amounts of warming would lead to greater values for sea level rise). The range spans from 20 inches to nearly 5 feet of sea level rise (0.5-1.4m) for the California coast.

The relatively large range of sea level rise estimates underscores some of the uncertainty in the amount of warming that could occur by the end of the 21st century. In addition, our understanding of the mechanisms associated with sea level rise (e.g., rates of melting of the ice caps, rates of melting of mountain glaciers) are rapidly evolving, and recent revisions to global sea level rise estimates have consistently been toward faster rates (i.e., previous values are now considered to be underestimates).

Although significant sea level rise is projected for the California coast (Cayan et al., 2009), most of Metro's current services and assets are not in areas that are likely to be affected (see Figure 15). The only potential areas of concern are the Long Beach light rail stations on the Blue Line and the portion of the Blue Line near the Los Angeles River (between the Del Amo and Wardlow stations). However, the fact that the Long Beach stations serve as a terminus, and that the area of track near the River is elevated helps to minimize the overall sensitivity.

For new projects, the locations of the current and projected future floodplains should be taken into account as part of the planning process. However, the overall risk to Metro, especially when compared to other regions in the United States like the Gulf Coast, is relatively low.

Figure 15: Map of the 100-year Flood Inundation Area in 2000 and in 2100 Assuming a 1.4m Sea Level Rise



3.4. Assessing Vulnerability and Presenting Potential Adaptation Options

Focusing on extreme heat events and episodes of heavy rainfall, the following sections describe how critical assets are vulnerability to climate impacts and outline some potential adaptation options. Given the screening nature of the adaptation study, the assessment of vulnerability is qualitative and the adaptation options presented are not prescriptive, but merely illustrative examples.

Assessing Vulnerability

The vulnerability of a service or asset is a function of its exposure, sensitivity, and adaptive capacity with respect to a particular impact of climate variability or change. Each of these three concepts is described below, focusing on examples of periods of extreme heat and episodes of heavy precipitation:

- **Exposure—**Is the service or asset exposed or protected from extreme heat or heavy precipitation? (e.g., assets located underground are not as exposed to high temperatures as assets located aboveground)
- **Sensitivity—**If exposed, does extreme heat or heavy rain cause damage or negatively affect the service or asset? Are there thresholds at which impacts occur? (e.g., air conditioning units start to break down and cause damage around 100°F; rail buckling can begin around 110°F)
- ***Adaptive Capacity*—**Which assets are most easily replaced? Which can be moved or changed to reduce exposure or sensitivity? (e.g., buses are mobile and can be moved in response to or anticipation of flooding)

Table 13 and Table 14 show the results of a qualitative assessment of the exposure, sensitivity, and adaptive capacity for critical assets.

Table 13: Summary of Vulnerability Analysis for Extreme Heat Events

Darker shading indicates higher degree of vulnerability.

Critical Asset	Exposed to Extreme Heat?	Sensitivities	Adaptive Capacity	Vulnerable?
Bus Fleet	Yes	Equipment failure and higher frequency of breakdown	Moderate: Bus fleet is relatively large	Yes
Bus Rapid Transit right-of-way (Silver and Orange Lines)	Yes	Pavement degradation can be accelerated	Moderate: Pavement likely to be replaced relatively frequently	Possible: (depending on the expected frequency of pavement replacement)
Heavy Rail (Red and Purple)	Minimal (underground)	Some station systems (electrical, air conditioning) may not function optimally	Moderate: Most systems can be inspected (in anticipation of heat events) or repaired/replaced	Possible: (depending on frequencies of occurrence and stations affected)
Light Rail (Blue, Green, and Gold)	Yes	Rail buckling and higher risk of equipment (e.g., electrical systems, air conditioning) failure	Moderate: Operations can be modified (e.g., speed reductions), but damage to rails can still occur	Yes
Measure R construction work	Yes	Construction speed[16] and worker health can be compromised by extreme heat	Moderate: Construction schedules can be modified; exposure could be lowered depending on mode choices and locations	Yes
Measure R planned assets	Possible	Above sensitivities and adaptive capacity apply, depending on mode choices and locations		Possible

[16] Cal/OSHA Heat Illness Prevention Standard requires that construction workers have access to shade when the temperature exceeds 85°F. Employers of construction workers are required to implement high-heat procedures when the temperature equals or exceeds 95°F.

Table 14: Summary of Vulnerability Analysis for Extreme Precipitation Events

Darker shading indicates higher degree of vulnerability.

Critical Asset	Exposed to Extreme Precipitation?	Sensitivities	Adaptive Capacity	Vulnerable?
Bus Fleet	Yes	Bus service may be limited when streets flood, but buses are likely to avoid being damaged.	High: buses can be moved and re-routed to avoid flooded areas	Possible: buses are unlikely to be vulnerable, but the service through flooded locations is vulnerable
Bus Rapid Transit right-of-way (Silver and Orange Lines)	Yes	At-grade locations could experience flooding, but existing BRTs not in floodplains	Low: Right-of-ways are stationary	Possible
Heavy Rail (Red and Purple Lines)	Yes	Stations and tunnels typically flood when nearby streets flood; doors to equipment rooms and electrical systems at risk	Low: Rail is stationary; alternative routing options are limited for some locations; pumping capacity is finite	Yes
Light Rail (Blue, Green, and Gold)	Yes	Similar to BRTs, at-grade locations could experience flooding; elevated rail has lower sensitivity	Moderate: Rail is stationary	Yes
Measure R planned assets	Possible	Above sensitivities and adaptive capacity apply, depending on mode choices and locations		Possible

Potential Adaptation Options

We identified several activities that Metro could consider in its efforts to increase its resilience to climate impacts, specifically those impacts associated with extreme heat events and episodes of heavy precipitation.

- **Improved Inspection and Monitoring—**To address many issues associated with equipment malfunctions and failure, Metro could investigate ways to enhance maintenance inspection and monitoring processes. Inspections for heat-sensitive systems (e.g., air conditioning in buses, electric systems for rails) could be performed regularly in the early spring, prior to the arrival of extreme heat events, to preemptively identify older or poorly functioning equipment that could fail if stressed by the heat.

  "Monitoring" might involve the documentation of the role that weather or climate plays in equipment replacements, upgrades, or repair. It is possible that such documentation could help Metro identify the parts of its system (locations and/or types of equipment) that are most sensitive to extreme heat and heavy precipitation. Also, such monitoring could, over time, serve as a metric for resilience itself. Theoretically, temperature- or precipitation-related repairs and replacements should decrease over time, or be done at less cost and more proactively (i.e., prior to the occurrence of service delays or interruptions).

- **Railway Upgrades**—Metro could investigate options for using more heat-resistant materials or designs for its railways (NRC, 2010) or improving the shading of sensitive track lines (either through construction of support structures or vegetation) to reduce the risk of buckling.
- **Stormwater Management**—Station entrances and ventilation grates typically allow runoff during heavy storms to result in the flooding of underground railway tunnels (Jacob et al., 2008). Similarly, uncontrolled runoff during periods of heavy precipitation can inundate at-grade railways. Metro could investigate the costs and benefits of augmenting stormwater management systems, whether they be “gray” (e.g., concrete structures design to retain or re-direct water) or “green” (e.g., rain gardens or other vegetation). Expansion of green infrastructure, where space is available, may also further Metro’s other goals for low-impact or sustainable construction.
- **Underground Station Upgrades**—Measures to reduce flooding in underground stations are being considered by other below-ground transit agencies. Some of these measures include changes to ventilation grates, repair and fortification of tunnel seals, addition of floodgates to entrances, redesign of entrances, addition of pumping capacity, and transition to “closed systems” for ventilation (Jacob et al., 2008).
- **Measure R Siting and Alternatives**—Mode choices and locations clearly have important impacts on vulnerability. Planned projects could be required to consider the effect of extreme heat and precipitation as part of their siting and alternatives analyses.
- **Worker Rules and Heat**—Construction schedules could be modified, especially during the summer months, to focus on night or early morning construction. Mid-day and afternoon periods will likely pose the worst threats to worker health and performance, with respect to both heat and air quality.

Summary of Vulnerabilities and Potential Adaptation Options

Table 15 provides a summary of the vulnerabilities identified in the adaptation study and some of the adaptation options that might be considered.

Table 15: Summary of Vulnerability Analysis and Potential Adaptation Options

Service/Asset	Climate Impact	Potential Adaptation Option
Rail Operations	Equipment malfunction (electrical systems; air conditioning systems) during periods of extreme heat	• Pre-emptive maintenance or inspection; weather/climate-related monitoring
	Railway buckling during periods of extreme heat	• More heat-resistant materials or designs, if available • Increased shading of railways
	Flooding of underground stations and tracks during heavy rainfall events	• Improved stormwater management systems • Infrastructure upgrades in stations (ventilation grates, entrances, seals) • Increased pumping capacity
	Flooding of at-grade railways and (Bus Rapid Transit right-of-ways[17]) during heavy rainfall events	• Upgraded stormwater management systems
Bus Operations	Fleet breakdowns and maintenance during periods of extreme heat	• Pre-emptive maintenance or inspection; weather/climate-related monitoring
New Construction/ Measure R Projects	Exposing new infrastructure to episodes of extreme heat and heavy rainfall events	• Integration of climate considerations in siting and alternatives decisions
	Labor interruptions or delays during periods of extreme heat	• Modification of construction schedules, especially during summer months

[17] Although BRTs are part of Bus Operations, the right-of-ways are functionally more similar to a railway.

4. Next Steps

4.1. Reducing Greenhouse Gas Emissions

This Plan provides a framework for analyzing Metro's opportunities to reduce GHG emissions. It demonstrates that Metro could meet a goal of reducing the agency's GHG emissions per boarding by 5.0% from 2010 to 2020 while saving money. The Plan further recommends that decisions to support any individual strategy should be made based on a composite assessment of all potential benefits and costs of a strategy, rather than GHG impacts alone.

Metro's sustainability program continues to produce technical analyses that examine new options to reduce GHG emissions. This Plan can be updated as new information becomes available and new GHG reduction opportunities surface. Next steps for the Plan include:

- Establish an interdepartmental working group to monitor the implementation of strategies and progress towards reduction goals. This group could also schedule regular check-ins on emerging technologies.
- Update the Plan with analyses of strategies that reduce emissions from regional transportation, such as strategies that promote transit use, carpooling, and bicycling.
- Update the Plan with new information every 5 years, or more often if significant changes in technology, policy, or legal requirements warrant more frequent updates.
- In future plan updates, include a section on local, state, and federal regulations that directly affect Metro's GHG emissions, such as new vehicle technology regulations.
- Use the annual Sustainability Report to document strategies selected for implementation and monitor progress.

4.2. Adapting to the Effects of Climate Change

The Plan presents a high-level analysis that identifies some of Metro's major vulnerabilities with respect to climate variability and climate change. The Plan is essentially a first step toward improving Metro's resilience to climate impacts. As Metro moves toward evaluating specific adaptive actions, it will require more detailed information about climate impacts and adaptation options in order to inform its decisions. To this end, several next steps could be pursued:

- **Investigate climate vulnerabilities at a higher level of specificity** – The analysis presented in the Plan is largely focused at the service level (i.e., vulnerability to the Bus Fleet or Heavy Rail lines). There are likely specific areas or types of equipment within the Metro network that are susceptible to impacts (e.g., places within tunnels where flooding typically occurs or is most severe; types of equipment in facilities or vehicles that tend to experience problems during heat waves). Collecting information about these locations and equipment would be helpful in evaluating and guiding adaptation actions.
- **Explore the monetary and social costs of climate impacts and adaptation options** – It would be useful to estimate the social and economic costs borne by Metro, its customers, and the regional economy that result from the incidences of extreme heat and episodes of

heavy rainfall. Understanding these costs can help justify investments in adaptation and inform efforts to prioritize among adaptation options. In addition, the potential costs and savings associated with particular adaptation options (e.g., the costs associated with upgrades in infrastructure, potential savings associated with changes in operational protocols related to maintenance or construction) could be investigated to provide a more comprehensive view of the overall costs and benefits associated with pursuing adaptation.

- **Develop a strategy for communicating the adaptation component of the Plan, and subsequent adaptation activities** – As Metro continues to gather information about its vulnerability to climate variability and climate change and explore options for adaptation, it will likely need to communicate its vision and goals to its staff and its customers. Metro could begin by developing a communication strategy (e.g., selecting target audiences, identifying effective messages and images, utilizing appropriate media outlets) for sharing the important results of the Plan, especially those related to adaptation. The initial communication strategy associated with the Plan could be updated as Metro began to identify and pursue specific adaptation measures.
- **Explore implementation of climate adaptation principles at the operations level through the FTA-funded Climate Adaptation Pilot Program** – The objectives of the Pilot Program are to: 1) Capitalize on Metro's current climate change adaptation work and link these results to Metros's organizational structure and activities including the development of implementation tools using Environmental Management System Principles; 2) Develop a set of metrics against which adaptation strategy performance could be measured; and 3) Develop and implement an outreach plan to create and integrate climate adaptation awareness in other sectors of the region.

Reducing Greenhouse Gas emissions and implementing adaptive actions are companion efforts both aimed at ensuring Metro's operations are as sound as possible. Moving forward, Metro will develop a timeline of implementation concurrent with the FTA pilot effort for both mitigation and adaptation strategies, and use the most recent emissions data available during Plan updates.

5. Appendices

5.1. Inventory and Forecast Detailed Methodologies

Internal Inventory and Forecast

The internal inventory and forecast refers to the emissions produced by Metro. These include emissions from fuel combustion occurring in Metro vehicles, purchased transport, facilities, water use, and on-site use of high global warming potential (GWP) gases.

Two existing documents provide the basis for the internal inventory and forecast: the 2012 Sustainability Report and the Energy Conservation and Management Plan (ECMP). The 2012 Sustainability Report outlines Metro's annual impact on the environment along with suggested measures to reduce this impact.[18] The Sustainability Report contains an inventory of Metro's GHG emissions in 2010, including emissions from fuel combustion occurring in Metro vehicles, purchased transport, facilities, and on-site use of high GWP gases. The inventory methodologies below reflect the calculations performed in compiling the Sustainability Report.

The ECMP is a strategic blueprint intended to guide Metro's energy use in future years.[19] It contains forecast growth rates for energy use in specific sectors including building energy, rail transport, and bus transport. The ECMP also contains a list of planned rail expansions that are expected to be operational by 2020.

Emissions associated with gasoline and diesel combustion in the buses were calculated using CO_2, CH_4, and N_2O emission factors from the Climate Registry.[20] CO_2 emissions from CNG combustion are from the Department of Energy's website.[21] CH_4 and N_2O emission factors from CNG are also from the Climate Registry.[22]

The following sections describe the methods and assumptions used to compile inventory and forecast emissions totals for each sector.

Transport

CNG Buses

The majority of Metro's transit buses is now fueled by natural gas. CO_2 emissions from transit CNG use were calculated from the CNG fuel use data provided by Metro for the calendar year

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18 Los Angeles County Metropolitan Transportation Authority (LACMTA). (2012) *Moving Towards Sustainability: 2012 Metro Sustainability Report Using Operational Metrics*. Prepared by ICF International. Los Angeles.

19 LACMTA. (2011) *Energy Conservation and Management Plan*. Draft. March. Prepared by ICF International. Los Angeles.

20 California Climate Action Registry (CCAR). 2009. *California Climate Action Registry general reporting protocol reporting entity-wide greenhouse gas emissions*. *Version 3.1*. Sacramento, Calif. Available at: http://www.climateregistry.org/tools/protocols/general-reporting-protocol.html. Accessed November 21, 2011: Table C.3, C.4, and C.5

21 US Department of Energy (DOE). 2010. Alternative Fuels & Advanced Fuels: Gallons of Gasoline Equivalent (GGE) Definition. Available at: https://www.afdc.energy.gov/afdc/prep/popups/gges.html. Accessed November 21, 2011

22 CCAR, 2009:Table C.5

2010. CH_4 and N_2O emissions were calculated from the CNG transit mileage data provided by Metro for the calendar year 2010.

Metro's 2009 Long Range Transportation Plan (LRTP) assumes that bus ridership will grow by 0.7% annually.[23] 2020 emissions are forecast assuming an equivalent rate of growth in bus mileage and fuel usage. This method assumes that average vehicle load factors, average vehicle fuel economy, and the carbon intensity of CNG fuel remain constant to 2020.

Gasoline and Diesel Revenue Transport

A small percentage of Metro's transit service still used gasoline and diesel fuel in 2010. Diesel and gasoline consumption by Metro buses was estimated using fuel consumption and vehicle mileage estimates provided by Metro. CH_4 and N_2O emissions were calculated from transit mileage data provided by Metro

Because Metro is planning to phase out gasoline and diesel fuel use in their revenue fleet, there are no gasoline and diesel fuel emissions forecasted for 2020 from revenue vehicles.

Purchased Transport

Metro contracts with private bus operators to provide service in some parts of the County. Purchased transport uses diesel, propane, and CNG fuel. Emissions from these vehicles are included in the internal inventory.

Emissions from purchased transport were calculated from fuel consumption numbers provided by Metro for the calendar year of 2010. CH_4 and N_2O emissions were calculated from transit mileage data provided by Metro.

The same 0.7% growth rate applied to buses operated by Metro was applied to forecast emissions from purchased transport.[24] This method assumes that average vehicle load factors, average vehicle fuel economy, and the carbon intensity of CNG fuel remain constant to 2020.

Non-Revenue Transport

Non-revenue transport refers primarily to travel by Metro's employees in the agency's fleet of cars and light trucks. Metro's employees travel by car for construction, operations, and maintenance tasks, and for meetings. Some fuel used in maintenance equipment is also included in this category.

Diesel and gasoline consumption for non-revenue transport was estimated using fuel consumption estimates provided by Metro. These were in turn used to estimate CO_2 emissions. CH_4 and N_2O emissions from non-revenue transport were not calculated, due to a lack of mileage data.

The ECMP estimates that Metro will increase the total square footage of its facilities by 15% from 2010 to 2020. This estimate includes new stations and maintenance facilities along Metro's planned route expansions, as well as a new bus maintenance facility at Division 13.[25] The

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[23] LACMTA. (2009) *2009 Long Range Transportation Plan: Technical Document*. Los Angeles, page 57

[24] Ibid.

[25] LACMTA, (2011) *Energy Conservation and Management Plan*, September 2011, page 2-22

forecast assumes a proportional increase in Metro employees and in travel in non-revenue vehicles. Accordingly, a 15% increase was applied to forecast non-revenue fuel use in 2020. Emissions were adjusted to account for expected improvements in fuel economy, per state and federal regulations.

Rail

Emissions from the electricity used for rail were calculated from total electricity usage from the operational rail lines in 2010, provided by Metro. Utility specific emission factors were applied based on the utility from which the electricity was purchased for each line.

Emissions from the rail system were forecast according to assumptions in the ECMP. Energy use on existing rail segments is forecast to grow by 1.2% annually. Emissions from new rail segments to be operational by 2020 were also forecast in the ECMP.[26] Future changes in electricity emission factors based on statewide renewable energy goals (Renewable Portfolio Standard) were applied to forecast emissions for 2020.

Vanpool

Emissions from Metro-operated vanpools were calculated from the total gallons of fuel usage in 2010, as provided by Metro. Forecasts for vanpool emissions in 2020 assume no growth in vanpool usage. Forecast emissions were adjusted to account for expected improvements in fuel economy, per state and federal regulations.

Facilities

Natural Gas Use

Natural gas is used on-site at facilities for heating and cooking purposes. Emissions result from on-site combustion of natural gas. The emissions inventory from facility natural gas use was calculated from the total therms reported in 2010 billing data from The Gas Company provided by Metro.

Natural gas use in facilities is expected to grow by 8% from 2010 to 2020, as forecast in the ECMP.[27] This forecast incorporates the planned expansion of facilities, the effect of expected higher ambient temperatures in 2020, and the impact of efficiency improvements pursuant to Title 24 and Metro's goals for LEED certification of facilities.

Electricity Use

Electricity is used for lights, appliances, computers, and other electronics and operations at Metro facilities. Facility electricity usage was calculated by subtracting rail electricity use from the total of electricity use indicated in the company-wide electricity bills for 2010, as provided by Metro. Utility specific emission factors were applied based on the utility from which the electricity was purchased for each facility.

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26 LACMTA, *Energy Conservation and Management Plan*, September 2011, page 2-14

27 LACMTA, *Energy Conservation and Management Plan*, September 2011. Growth in natural gas use is provided in unpublished background calculations.

Electricity use in facilities is expected to grow by 12% from 2010 to 2020, as forecast in the ECMP.[28] This forecast incorporates the planned expansion of facilities, the effect of expected higher ambient temperatures in 2020, and the impact of efficiency improvements pursuant to Title 24, AB1109, and Metro's goals for LEED certification of facilities. Future changes in electricity emission factors based on statewide renewable energy goals (Renewable Portfolio Standard) were applied to forecast emissions for 2020.

Water Use

Metro uses water in faucets and toilets, as well as for washing buses and rail cars. Water use indirectly produces GHG emissions, due to the electricity needed to convey, distribute, and treat water.

Emissions are calculated from company-wide total water use in 2010 utility bills provided by Metro. Electricity-intensity factors in Los Angeles for water transport and treatment come from a report by the California Energy Commission.[29]

Water use is assumed to increase in proportion to the square footage of Metro's facilities, or 15% from 2010 to 2020.

High GWP Gases

SF6 Use

SF6 is used as an electrical insulating gas, namely in electrical applications for the rail infrastructure. A small percentage of SF6 used leaks from the system and escapes into the atmosphere. Estimated emissions of SF6 are based on leakage estimates provided by Metro. Emissions of SF6 are forecast to increase proportionally with use of electricity in Metro's rail system.

Refrigerants

Refrigerants are used in both building and vehicle climate control systems, as well as in refrigerators. A small percentage of refrigerants leaks from the system and escapes into the atmosphere. Estimated emissions of refrigerants are based on purchase and inventory records provided by Metro. Annual purchases of refrigerants are assumed to replace gases that have escaped into the atmosphere.

Refrigerant leakage from vehicles is assumed to grow in proportion to passenger miles traveled (PMT). PMT was forecast assuming an average annual growth rate of 1% on existing bus and rail lines plus PMT expected on route extensions. New projects expected to be operational in 2020 are outlined in the ECMP. PMT on these segments was forecast assuming an average ratio of PMT per track mile, as derived from Metro's 2009 operating statistics.

Refrigerant leakage from facilities was forecast assuming growth in proportion to the growth in square footage of built space.

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28 LACMTA, September 2011, *Energy Conservation and Management Plan*. Growth in electricity use is provided in unpublished background calculations.

29 California Energy Commission (CEC). (2006) *Refining estimates of water-related energy use in California PIER final project report*. Sacramento, Calif.

Displaced Emissions Inventory

The APTA Protocol defines "displaced emissions" as external emissions that are avoided through the provision of transit service. These include emissions that are avoided through mode shift, congestion reduction, and indirect land use benefits. Metro's displaced emissions from mode shift were calculated in the 2012 Sustainability Report, according to guidance in the APTA Protocol.

Reductions from mode shift were calculated using the total number of passenger miles traveled (PMT) on Metro transit in 2010, 2.05 billion PMT. This total was multiplied by a mode shift factor of 0.47, as recommended by APTA for large areas of over 1.25 million people.[30] Displaced travel was converted to displaced fuel use by applying average fuel economy estimates from the Annual Energy Outlook.[31]

Emissions from Private Vehicles in Los Angeles County

Travel in private vehicles in Los Angeles County produces a substantial amount of GHG emissions. These emissions are not under the control of Metro; however, it is useful to understand the scale of these emissions as they compare to emissions produced and displaced by Metro. There is an inherent tradeoff between emissions from transit service and emissions from private vehicles.

Daily VMT estimates for 2004 and 2030 were drawn from the 2009 LRTP.[32] The figures represent travel by Los Angeles County residents. It was assumed that these VMT represent light duty passenger vehicles. VMT estimates for 2010 were interpolated. Per mile emission factors from standard sources were then applied to estimate total GHG emissions from private vehicle travel in Los Angeles County.[33]

[30] This mode shift factor represents the transfer of travelers who originally rode transit that would drive private vehicles instead, if public transportation was not available. (American Public Transportation Association (APTA). 2009. *Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit.* APTA Climate Change Standards Working Group. APTA CC-RP-001-09: page 34)

[31] US Office of Energy Information Administration (EIA). 2011. *Annual Energy Outlook - 2011.* Washington, D.C.

[32] Daily figures were multiplied by a factor of 307.5 to convert to annual figures.

[33] MPG Source: US Office of Energy Information Administration (EIA). 2011. *Annual Energy Outlook - 2011.* Washington, D.C, Table 7 - LDV stock;
N20 and CH4 Source: US Environmental Protection Agency (EPA). (2011). *2011 Inventory of U.S. Greenhouse Gas Emissions and Sinks.* 430-R-11-005. Washington, D.C - Table A-101 - average of EPA Tier 2 emissions for gasoline passenger cars and gasoline light-duty trucks

5.2. Measure Screening Memorandum

Below is the October 31, 2011 memorandum that described the screening process used to select the measures to analyze for this Plan.

ICF INTERNATIONAL

MEMORANDUM

To: Cris Liban, Los Angeles Metro
From: Frank Gallivan and Jeff Ang-Olson, ICF
Date: October 31, 2011
Re: Screening of GHG Measures for Climate Action Plan

This memo summarizes our recommendations for GHG reduction measures to be analyzed for inclusion in Metro's Climate Action Plan. There are a large number of potential GHG reduction measures, and it is not feasible for the ICF team to analyze every potential measure given the time and resources needed to research and quantify benefits and costs. Therefore, we conducted a screening exercise to identify a recommended short list of measures to analyze. We developed these recommendations using the following three-step process:

1) Identify potential measures
2) Assess and rank measures in terms of benefits, costs, implementation timeframe, and data availability
3) Select measures

We describe each of these three steps below, followed by a list of the recommended measures.

Identify potential measures

We reviewed a variety of documents to identify possible GHG reduction measures. All sectors and emission sources types were considered, including VMT reduction, vehicle technology and fuels, building and facility energy, renewable energy, water use, and recycling and waste management. Our document review included recent studies for Metro, such as:

- GHG Reduction Cost Effectiveness Study
- Water Action Plan
- Energy Conservation and Management Plan
- Renewable Energy Plan
- Moving Towards Sustainability: 2010 LACMTA Sustainability Report
- Green Construction Policy

We also reviewed reports describing GHG mitigation measures considered by other transit agencies, including:

- SamTrans Sustainable Return on Investment Analysis
- BART Actions to Reduce Greenhouse Gas Emissions: A Cost-Effectiveness Analysis

620 Folsom Street, Suite 200 — San Francisco, CA 94107 — 415.677.7100 — 415.677.7177 fax — icfi.com

- TCRP Synthesis 84: Current Practices in Greenhouse Gas Emissions Savings from Transit
- FTA's Transit Greenhouse Gas Emissions Management Compendium
- APTA's Transit Sustainability Practice Compendium

Through this process we identified approximately 80 potential measures. Some of these measures were duplicative or contained overlapping components, so the list was consolidated to contain only unique measures. We removed from the list any measures that have already been undertaken by Metro (and have little or no potential for expansion) as well as a small number of measures that we considered infeasible (e.g., use of biodiesel). This resulted in a list of approximately 50 measures.

Assess and rank measures

In order to prioritize measures for quantification and potential inclusion in the Climate Action Plan, we assessed each potential measure using four factors. Each measure was scored on a scale of 0 to 30, with weights assigned to the four assessment factors. The table below shows the factors and associated weighting.

Factor	Weight
Data availability / Ability to quantify benefits	30%
Additional GHG reduction potential	40%
Timeframe for implementation	10%
Cost per ton of GHG reduction (relative to other measures)	20%

The highest scoring measures where those considered easy to quantify, having a large potential GHG reduction, a short timeframe for implementation, and relatively low cost per ton of GHGs reduced. Table 1 shows the results of this measure assessment and scoring.

The weighting applied to the measure assessment factors is based on the professional judgment of the ICF team. Alternative weighting schemes were also tested, with little impact on measure ranking. The purpose of this exercise is not to rigorously apply a formula for selecting measures, but simply to aid in prioritization. After scoring and ranking all the potential measures, we reviewed the results to identify any measures that we felt deserved consideration despite a low score or deserved omission despite a high score.

Table 1: Scoring of Potential GHG Reduction Measures

Measure	Category	Total Score
On-board Railcar Braking Energy Storage	Vehicle Technology	28
Employer-Based TDM: Outreach and Transit Pass Programs	Offset VMT	27
Vanpools	Offset VMT	25
Building Indoor Lighting Upgrades	Building Energy	25
Transit Oriented Development	Offset VMT	24

Measure	Category	Total Score
Expand Transit Service (bus and rail)	Offset VMT	24
Wayside Energy Storage Substation (WESS)	Vehicle Technology	24
Install more photovoltaics, to double Metro's RE generation	Renewable Energy	23
Mobile Air Conditioning Replacement	Vehicle Technology	22
Recycled Water For Bus Washing	Water Use	22
Extension of Bus Wash On-Site Reclamation	Water Use	22
Low Water Sanitary Fixtures	Water Use	22
Retrofit Lighting in Red Line Tunnel	Building Energy	21
Metro Employee Transit Subsidy Program	Offset VMT	20
Bicycle Paths along Transit Corridors	Offset VMT	20
Personalized Travel Outreach (e.g., SmartTrips)	Offset VMT	20
Gasoline-Electric Hybrid or CNG Hybrid Buses	Vehicle Technology	20
Submeter electricity use of every building	Building Energy	20
On-Site Gray Water Reclamation with Standard Fixtures	Water Use	20
Replacement of Steamer	Water Use	20
Municipal Recycled Water For Landscape Irrigation	Water Use	20
Replacement Engine Compartment Cleaner	Water Use	20
Replacement of Under Chassis Washer	Water Use	20
Replacement of Small Parts Washer	Water Use	20
Bike-to-Transit Commuter Incentives	Offset VMT	19
Reduce Bus Dead-head Miles	Offset VMT	19
PHEVs or BEVs for Non-Revenue Fleets	Vehicle Technology	19
Weather stripping on doors and caulk windows	Building Energy	19
Desktop Computer Management System	Building Energy	19
Enhance Recycling	Waste Management	19
Battery Electric Buses	Vehicle Technology	18
Outdoor Lighting Upgrades	Building Energy	18
Install occupancy sensors for lights in offices	Building Energy	18
Install photo-sensors for outdoor lighting	Building Energy	18
Programmable digital thermostats w/ automatic setback temps	Building Energy	18
Adjust Existing Transit Service (bus)	Offset VMT	17
Battery Upgrade in CNG Buses	Vehicle Technology	17
Upgrade older HVAC and boiler equipment	Building Energy	17
Construct new facilities to LEED and CALGreen guidelines	Building Energy	17
Wind Energy in Subway Tunnel	Renewable Energy	17
45-foot Composite Buses	Offset VMT	16
Implement bus idling reduction policy	Vehicle Technology	16
Support and market inter-agency transit pass program	Offset VMT	15
Install and optimize BAS for all buildings	Building Energy	15

Measure	Category	Total Score
Pursue LEED EBOM certification at other sites	Building Energy	15
Hydrogen/CNG Blend in Buses	Vehicle Technology	14
Consider retro-commissioning of select sites	Building Energy	14
Install windows in maintenance bldgs to reduce need for lighting	Building Energy	13
Hire a systems engineer to provide support and training on BAS	Building Energy	11

Select measures

Using the assessment and ranking described above, we have identified 17 measures for analysis and potential inclusion in the Climate Action Plan, listed in Table 2. These measures all received a score of 20 or higher, using the assessment process described above.

Table 2: Measures Recommended for Analysis and Potential CAP Inclusion

Number	Measure	Category
1	On-board Railcar Braking Energy Storage	Vehicle Technology
2	Employer-Based TDM: Outreach and Transit Pass Programs	Offset VMT
3	Vanpools	Offset VMT
4	Building Indoor Lighting Upgrades	Building Energy
5	Transit Oriented Development	Offset VMT
6	Expand Transit Service (bus and rail)	Offset VMT
7	Wayside Energy Storage Substation (WESS)	Vehicle Technology
8	Install more photovoltaics, to double Metro's RE generation	Renewable Energy
9	Mobile Air Conditioning Replacement	Vehicle Technology
10	Recycled Water For Bus Washing	Water Use
11	Extension of Bus Wash On-Site Reclamation	Water Use
12	Low Water Sanitary Fixtures	Water Use
13	Retrofit Lighting in Red Line Tunnel	Building Energy
14	Bicycle Paths along Transit Corridors	Offset VMT
15	Personalized Travel Outreach (e.g., SmartTrips)	Offset VMT
16	Gasoline-Electric Hybrid or CNG Hybrid Buses	Vehicle Technology
17	Submeter electricity use of every building	Building Energy

Several measures that received a score of 20 are not recommended for CAP analysis, for the following reasons:

- Metro Employee Transit Subsidy Program – this measure is currently in place at Metro and is expected to continue in its present form. The potential for additional GHG reduction (beyond the current reduction) is small.
- On-Site Gray Water Reclamation with Standard Fixtures, Replacement of Steamer, Municipal Recycled Water for Landscape Irrigation, Replacement Engine Compartment

Cleaner, and Replacement of Under Chassis Washer – these measures all involve reduction in water use. While relatively cost effective, the potential GHG reduction from these measures is very small.

Note that the Climate Action Plan may identify and describe additional measures, but without quantification of benefits and costs.

Next Steps

We are requesting feedback from the Metro Technical Advisory Committee (TAC) on the recommended measures.

5.3. Measures—Detailed Analysis Methodologies

This appendix provides a more detailed description of the analysis methodology for each strategy described in section 2.3. The analysis builds on Metro's Greenhouse Gas Emissions Cost Effectiveness Study. Since that report came out in June 2010, new information has become available for some strategies. Those analyses have been updated in this memo to reflect that information. Some analysis assumptions and calculation have also been refined. Three additional strategies not considered in the Cost Effectiveness Study were analyzed here, following the approach used in the Cost Effectiveness Study. The Cost-Effectiveness Study can be accessed online at: http://www.metro.net/projects_studies/sustainability/images/GHGCE_2010_0818.pdf.

The details contained in the Cost Effectiveness Study are not repeated here, except where changes have been made.

Two of the strategies analyzed would have impacts on GHG emissions beyond those included in Metro's GHG inventory. The gasoline hybrid electric buses and the use of biomethane have impacts on GHG emissions that occur upstream in the fuel cycle. That is, they would affect GHGs emitted in the production of fuels, before the point that gasoline and natural gas reach Metro's facilities. Metro has the option to incorporate these upstream impacts in its Plan. In the case of the biomethane strategy, the GHG emission reduction benefits occur exclusively upstream.

Vehicle Technology Strategies

On-board Storage of Regenerative Braking Energy

The Cost Effectiveness Study analyzed the potential for on-board storage of regenerative braking energy on an individual rail car, using an auxiliary unit installed on the car. For the purposes of this Plan, we assume that 25% of existing railcars would be retrofitted with the technology by 2014 and 100% of the fleet (both existing and new vehicles) would have the technology by 2020. Our calculations account for the assumed increase in the railcar fleet due to system expansion. The fleet was increased in proportion to the assumed growth in power consumption between 2010 and 2020. Additional technical details are provided in the Cost Effectiveness Study.

Wayside Energy Storage Substations (WESS)

Metro has begun a wayside storage pilot project, funded through a $4.5 million TIGGER grant from the Federal Transit Administration. The Red Line Westlake Energy Storage System will capture and release energy at the Westlake at-grade rail station. Metro has issued a request for proposals for the design and construction of this system as of early 2012 and expects the pilot system to be operational as of 2014. The Cost Effectiveness Study analyzed the potential for wayside energy storage at a single substation.

Given that the first WESS system is not expected to be operational until 2014, we do not expect that Metro would be able to install WESS systems at all stations by 2020. Instead, for the purposes of the Plan, we assume that one station would have this technology in place by 2014 and that 30 stations (approximately half of Metro's current stations) would have WESS systems by 2020. Additional technical details are provided in the Cost Effectiveness Study.

Mobile Air Conditioning Replacement

Metro's bus fleet currently uses HFC-134a, which has a relatively high global warming potential (GWP). Newer refrigerants with much lower global warming potentials have been developed and are seeing their first applications in transportation. Though starting in the automotive sector, the refrigerants are expected to be available for other vehicles, including buses, in the near future.

HFO-1234yf appears to be the preferred replacement refrigerant of the automotive industry in Europe and the U.S. While not yet approved for use in heavy-duty vehicles, there have been tests of buses in Spain by a major mobile air conditioner manufacturer, indicating that the refrigerant is a near drop-in replacement.[34] It is expected that the new refrigerant will initially be used in new units primarily, with limited retrofits. HFO-1234yf has a GWP of 4 compared to HFC-134a's GWP of 1,430.

Metro overhauls all of its buses at the mid-point of their 15-year lifespan, providing an opportunity to change the refrigerant at that point; however, older buses may need to be retrofit in order to accommodate the new refrigerant. For the purposes of the Plan, we assume that the replacement refrigerant for HFC-134a will be HFO-1234yf. We assume that the new refrigerant will initially only be installed in new buses, starting in 2014. The air conditioning unit on a new 40-foot Metro bus carries approximately 8 pounds of refrigerant, and the estimated refrigerant leakage rate for new urban buses is 13.7% per year.[35] Therefore, a new bus typically leaks about 1.1 pounds of refrigerant per year. Older buses leak refrigerant at a higher rate, closer to 25% based on Metro's current refrigerant use, and carry larger charges of refrigerant. The lower rate of 13.7% was confirmed as a reasonable estimate by the Metro Vehicle Technology Department.

The price of HFO-1234yf is currently much higher than that of HFC-134a. As production of the new refrigerant ramps up internationally, prices are expected to fall. We use industry estimates of the expected near term cost for wholesale purchases by service shops ($70/lb)[36] and California Air Resources Board's (CARB) estimates for the price reduction over time. CARB projects that the price of HFO-1234yf will fall 20% every two years from model year 2012 to model year 2020.[37] New service equipment may be required to handle HFO-1234yf; however, costs for such equipment are excluded since no estimates are readily available.

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34 Genetron® Refrigerants Europe, "Honeywell's Low-Global-Warming Refrigerant Successfully Tested for Use in Bus Air-Conditioning Systems," News Release, 6 September 2011. Available at: http://www51.honeywell.com/sm/chemicals/refrigerants/eu/en/news-n2/news-details/11-09-06.html (Last accessed 1 February 2012)

35 "Refrigerants are becoming increasingly important," Konvekta AG Research and Development, 2011. Available at: http://www.konvekta.de/index.php?id=1953&L=1 (Last accessed 31 January 2012)

36 "SAE publishes 18 standards on new A/C refrigerant HFO-1234yf," *Automotive Design*, 15 February 2011. Available at: http://www.automotivedesign.eu.com/article/35107/SAE-publishes-18-standards-on-new-AC-refrigerant-HFO-1234yf.aspx (Last accessed 26 January 2012)

37 California Air Resources Board, "Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Public Hearing to Consider the 'LEV III' Amendments, Appendix R: Technical Support Document—Proposed LEV III Greenhouse Gas Non-Test

Gasoline-Electric Hybrid Buses

This strategy was explored in the Cost Effectiveness Study; however, the present analysis updates several of the assumptions used in that study. Emission factors used in the Cost Effectiveness Study were updated to reflect emission factors for reformulated gasoline in California. Likewise, prices for gasoline were updated to reflect forecasted prices for reformulated gasoline developed by the California Energy Commission.[38]

Biomethane in CNG Buses

The assumptions behind this analysis are all reported in section 2.3.

Building Energy Strategies

Facility Lighting Upgrades

The assumptions behind this analysis are all reported in section 2.3.

Expand Use of Renewable Energy

The assumptions behind this analysis are all reported in section 2.3.

Retrofit Lighting in Red Line Tunnel

Since the Cost Effectiveness Study was completed, Metro has selected an LED lighting technology to be used in the Red Line Tunnel. For the purposes of this Plan, we assume that all 5,808 74-watt two-lamp T8 fixtures currently installed in the Red Line Tunnel would be replaced by 2014 with 8,000 linear style LEDs of 35 watts per two-lamp fixture.

LEDs have a much longer lifespan than the current fixtures. As a result, Metro maintenance staff will not need to go into the tunnel as often to change out fixtures. This reduces both labor costs and vehicle emissions. The Cost Effectiveness Report did not examine the reduced vehicle emissions. Metro estimates that its hi-rail vehicles currently spend 4,000 hours per year in the tunnel for the purposes of changing the lights. Metro expects that it will only spend 600 to 960 hours annually replacing fixtures (the hours are spread over the lifetime of the fixtures). To be conservative, this analysis used the 960 hour estimate. The emission factor for vehicles is higher when idling than when the vehicle is traveling; therefore the 4,000 hours were split between idling and driving time based on an assumption that the vehicle travels the 22-mile tunnel twice a night at 5 miles per hour 6 days a week per year. The ratio of travel time to idling time was applied to the retrofit annual vehicle operating hours (960 hours). Emission factors were derived from EMFAC 2007 for medium-heavy duty trucks.

Cycle Provisions," released 7 December 2011. Available at: http://www.arb.ca.gov/regact/2012/leviiighg2012/levappr.pdf (Last accessed 26 January 2012)

[38] California Energy Commission (CEC). (2011) *Transportation Energy Forecasts and Analyses for the 2011 Integrated Energy Policy Report*, Draft Staff Report, CEC-600-2011-007-SD.

Water Use Strategies

Municipal Recycled Water for Bus Washing

The Cost Effectiveness Study and Metro's 2010 Water Action Plan analyzed the potential for using municipal recycled water for bus washing. For this Plan, the calculations for this strategy used in the Cost Effectiveness Study were updated to assume an expansion of the strategy to all Metro facilities.

Extension of Bus Wash On-Site Water Reclamation

Metro's Water Action Plan analyzed the potential for extending the bus washer floor grates and altering operational procedures to capture more run-off. For the purposes of this Plan, the extension of the floor grates and enforcement of procedures are assumed to increase runoff capture by 50 percent.

Low Water Sanitary Fixtures

The Cost Effectiveness Study and the Water Action Plan analyzed the potential for using low water sanitary fixtures in Metro facilities. For this Plan, the calculations for this strategy used in the Cost Effectiveness Study were updated to assume an expansion of the strategy to all Metro facilities. Additionally, reduced hot water needs were assumed to generate savings to Metro both for reduced water use costs and for reduced heating costs.

5.4. Asset and Service Inventory Analysis Background Data

Table 16: Criticality Information for Passenger Stations

Note: each station only appears once

Asset Type	Service Line	Asset Name	Service Volume		Real Estate	Connectivity			Overall Criticality Score	Criticality
						Transit				
			Sum of Boardings and Alightings (Daily Weekday)	Qualitative Rating		Parking (# Spaces, not including street parking)	Connectivity Rating	Qualitative Rating		
Connecting Stations										
Station	Blue, Green	IMPERIAL/WILMINGTON	18,162	High		975	10	High	6	Yes
Station	Red, Purple, Silver	CIVIC CENTER	6,206	High		0	50	High	6	Yes
Station	Red, Purple	WESTLAKE	9,116	High	Construction	0	15	High	7	Yes
Station	Red, Purple, Silver	PERSHING SQUARE	10,783	High		0	50	High	6	Yes
Station	Red, Purple, Gold	UNION STATION	29,514	High	Done	3,000	36	High	7	Yes
Station	Red, Purple	WILSHIRE/VERMONT	12,758	High	Done	0	5	Moderate	6	Yes
Station	Blue, Red, Purple, Silver	7TH/METRO CENTER	39,483	High	Done	0	50	High	7	Yes
Station	Red, Orange	NORTH HOLLYWOOD	16,093	High	Under negotiation	951	12	High	7	Yes
Station	Blue, Silver	PICO	2,554	Moderate		0	10	High	5	No
Station	Green, Silver	HARBOR FREEWAY	2,530	Moderate		253	13	High	5	No
BLUE LINE										
Station	Blue	103RD STREET	2,966	Moderate	Under negotiation	62	1	Moderate	5	No
Station	Blue	1ST STREET	837	Low		0	1	Low	2	No
Station	Blue	5TH STREET	1,604	Moderate		0	1	Low	3	No
Station	Blue	ANAHEIM	2,304	Moderate		0	1	Low	3	No
Station	Blue	ARTESIA	3,283	Moderate		380	3	Moderate	4	No
Station	Blue	COMPTON	3,639	Moderate		40	1	Moderate	4	No
Station	Blue	DEL AMO	3,040	Moderate		366	1	Moderate	4	No
Station	Blue	FIRESTONE	2,856	Moderate		0	3	Low	3	No
Station	Blue	FLORENCE	4,260	Moderate		100	2	Moderate	4	No
Station	Blue	GRAND	4,898	Moderate		0	12	High	5	No
Station	Blue	PACIFIC	687	Low		0	1	Low	2	No
Station	Blue	PACIFIC COAST HIGHWAY	2,204	Moderate		0	1	Low	3	No
Station	Blue	SAN PEDRO	2,087	Moderate		0	1	Low	3	No
Station	Blue	SLAUSON	2,227	Moderate		0	1	Low	3	No
Station	Blue	TRANSIT MALL	3,219	Moderate		0	1	Low	3	No
Station	Blue	VERNON	2,679	Moderate		0	2	Low	3	No
Station	Blue	WARDLOW	1,442	Moderate		92	1	Moderate	4	No
Station	Blue	WASHINGTON	1,591	Moderate		0	1	Low	3	No
Station	Blue	WILLOW	3,453	Moderate	Done	890	1	Moderate	5	No

Asset Type	Service Line	Asset Name	Service Volume		Real Estate	Connectivity – Transit			Overall Criticality Score	Criticality
			Sum of Boardings and Alightings (Daily Weekday)	Qualitative Rating		Parking (# Spaces, not including street parking)	Connectivity Rating	Qualitative Rating		
Rail Yard	Blue	Blue Line Rail Yard	N/A							??
Rail Facility	Blue	Location 60 - Blue Line Rail Central Control Facility	N/A							??
Storage	Blue	Long Beach Blvd. & Washington, L.A., Blue Line storage track (PE rail Maintenance of Way Satellite Yard)								??
GOLD LINE										
Station	Gold	ALLEN	1,139	Moderate		0	1	Low	3	No
Station	Gold	ATLANTIC	1,411	Moderate		266	2	Moderate	4	No
Station	Gold	CHINATOWN	1,170	Moderate		0 (under construction)	1	Moderate	4	No
Station	Gold	DEL MAR	1,122	Moderate	Done	290	2	Moderate	5	No
Station	Gold	EAST L A CIVIC CENTER	490	Low		0	1	Low	2	No
Station	Gold	FILLMORE	1,191	Moderate	Done	147	1	Moderate	5	No
Station	Gold	HERITAGE SQR/ARROYO	645	Low		129	1	Moderate	3	No
Station	Gold	HIGHLAND PARK	1,930	Moderate		0	1	Low	3	No
Station	Gold	INDIANA	953	Low		43	1	Moderate	3	No
Station	Gold	LAKE AVENUE	1,406	Moderate		100	1	Moderate	4	No
Station	Gold	LINCOLN HEIGHTS/CYPRESS PARK	930	Low		94	2	Moderate	3	No
Station	Gold	MARAVILLA	319	Low		0	1	Low	2	No
Station	Gold	MARIACHI PLAZA	606	Low	Under negotiation	0	1	Low	3	No
Station	Gold	MEMORIAL PARK	1,874	Moderate		0	2	Low	3	No
Station	Gold	MISSION	1,299	Moderate		118	1	Moderate	4	No
Station	Gold	PICO/ALISO	575	Low		0	1	Low	2	No
Station	Gold	SIERRA MADRE VILLA	2,674	Moderate	Done	1,100	1	Moderate	5	No
Station	Gold	SOTO	1,196	Moderate	Under negotiation	0	2	Low	4	No
Station	Gold	SOUTHWEST MUSEUM	654	Low		0	1	Low	2	No
Station	Gold	LITTLE TOKYO/ARTS DISTRICT	1,329	Moderate		0	2	Low	3	No
Rail Yard	Gold	Division 21 Pasadena Gold Line Yard (Midway)	N/A							??
Office	Gold	Gold Line Eastside Extension Office								??
GREEN LINE										
Station	Green	AVALON	2,320	Moderate		158	6	Moderate	4	No
Station	Green	AVIATION	3,533	Moderate		800	5	Moderate	4	No
Station	Green	CRENSHAW	2,725	Moderate		513	5	Moderate	4	No
Station	Green	DOUGLAS/ROSECRANS	665	Low		30	2	Moderate	3	No
Station	Green	HAWTHORNE	2,697	Moderate		623	7	Moderate	4	No
Station	Green	LAKEWOOD	2,363	Moderate		545	4	Moderate	4	No

Asset Type	Service Line	Asset Name	Service Volume		Real Estate	Connectivity – Transit			Overall Criticality Score	Criticality
			Sum of Boardings and Alightings (Daily Weekday)	Qualitative Rating		Parking (# Spaces, not including street parking)	Connectivity Rating	Qualitative Rating		
Station	Green	LONG BEACH	2,772	Moderate		650	4	Moderate	4	No
Station	Green	MARIPOSA/NASH	1,287	Moderate		0	1	Low	3	No
Station	Green	I-605/I-105	4,473	Moderate		2,050	9	Moderate	4	No
Station	Green	MARINE/REDONDO	1,024	Moderate		403	3	Moderate	4	No
Station	Green	EL SEGUNDO/NASH	942	Low		90	1	Moderate	3	No
Station	Green	VERMONT	2,905	Moderate		155	5	Moderate	4	No
Rail Yard	Green	(Green Line Yard & Shop--14724 Aviation Blvd., Lawndale)	N/A						2	??
PURPLE LINE										
Station	Purple	WILSHIRE/NORMANDIE	3,348	Moderate		0	2	Low	3	No
Station	Purple	WILSHIRE/WESTERN	4,622	Moderate	Done	0	4	Low	4	No
RED LINE										
Station	Red	HOLLYWOOD/HIGHLAND	8,297	High	Done	120	2	Moderate	6	Yes
Station	Red	HOLLYWOOD/VINE	5,378	High	Done	60	2	Moderate	6	Yes
Station	Red	VERMONT/SANTA MONICA	6,030	High	Under negotiation	0	3	Low	5	No
Station	Red	UNIVERSAL CITY	7,775	High	Under negotiation	390	2	Moderate	6	Yes
Station	Red	VERMONT/BEVERLY	4,603	Moderate		0	3	Low	3	No
Station	Red	VERMONT/SUNSET	4,767	Moderate		0	2	Low	3	No
Station	Red	HOLLYWOOD/WESTERN	5,254	High	Done	0	3	Low	5	No
Rail Yard	Red	Red Line Rail Yard	N/A							??
ORANGE LINE										
Station	Orange	Balboa Station	Unknown		negotiations	270	5	Moderate	4	No
Station	Orange	Canoga Station	Unknown			612	4	Moderate	3	No
Station	Orange	De Soto Station	Unknown			0	4	Low	2	No
Station	Orange	Laurel Canyon Station	Unknown			0	4	Low	2	No
Station	Orange	Pierce College	Unknown			373	3	Moderate	3	No
Station	Orange	Reseda Station	Unknown			522	3	Moderate	3	No
Station	Orange	Sepulveda Station	Unknown			1205	3	Moderate	3	No
Station	Orange	Tampa Station	Unknown			0	2	Low	2	No
Station	Orange	Valley College Station	Unknown			0	7	Moderate	3	No
Station	Orange	Van Nuys Station	Unknown			776	10	High	4	No
Station	Orange	Warner Center Station	Unknown			0	8	Moderate	3	No
Station	Orange	Woodley Station	Unknown			0	3	Low	2	No
Station	Orange	Woodman Station	Unknown			0	3	Low	2	No
SILVER LINE										
Station	Silver	El Monte Bus Station, Terminal 19	Unknown		Under negotiation	2,095	17	High	5	No
Station	Silver	California State University, Los Angeles	Unknown			0	9	Moderate	3	No

Asset Type	Service Line	Asset Name	Service Volume		Real Estate	Connectivity			Overall Criticality Score	Criticality
						Transit				
			Sum of Boardings and Alightings (Daily Weekday)	Qualitative Rating		Parking (# Spaces, not including street parking)	Connectivity Rating	Qualitative Rating		
Station	Silver	Los Angeles County-USC Medical Center	Unknown			0	10	High	4	No
Station	Silver	Spring St. & 1st St.	Unknown			0	5	Moderate	3	No
Station	Silver	Grand St. & 3rd St. (Southbound) Olive St. & Kosciuszko Way (Northbound)	Unknown			0	2	Low	2	No
Station	Silver	Flower St. & 5th St. (Southbound) Olive St. & 5th St. (Pershing Square) (Northbound)	Unknown			0	11	High	4	No
Station	Silver	Flower St. & Olympic Blvd. (Southbound) Figueroa St. & Olympic Blvd. (Northbound)	Unknown			0	8	Moderate	3	No
Station	Silver	Flower St. & Adams Blvd. (Southbound) Adams Blvd. & Figueroa St. (Northbound)	Unknown			0	6	Moderate	3	No
Station	Silver	37th Street	Unknown			0	10	High	4	No
Station	Silver	Slauson Station	Unknown			160	13	High	4	No
Station	Silver	Manchester Station	Unknown			127	11	High	4	No
Station	Silver	Rosecrans	Unknown			342	6	Moderate	3	No
Station	Silver	Artesia Transit Center	Unknown			900	9	Moderate	3	No
BUS TERMINALS, TRANSIT CENTERS, LAYOVERS										
Bus Layover	Bus	Terminal 17 -Maple Lot	N/A		N/A	N/A				??
Bus Layover	Bus	Terminal 28 - 18th St. Bus Layover								??
Bus Layover	Bus	Terminal 31 - Vignes Bus Layover								??
Bus Layover	Bus	Terminal 37 - Palm Place Loop Bus Layover								??
Bus Layover	Bus	Terminal 38 - 85th & Central Bus Layover								??
Bus Layover	Bus	Terminal 39 - Jefferson Loop Bus Layover								??
Bus Layover	Bus	Terminal 40 - Pico Rimpau Loop Bus Layover								??
Bus Layover	Bus	Terminal 41 - 6th & Wilton Bus Layover								??
Bus Layover	Bus	Terminal 42 - Echo Park & Donaldson Bus Layover								??
Bus Layover	Bus	Terminal 44 - Dozier & Rowan Layover								??
Bus Layover	Bus	Terminal 45 - Rose Hills Station Layover								??
Bus Layover	Bus	Terminal 53 - 117th St/ Figueroa Bus Layover								??
Bus Station	Bus	Terminal 48 - Cal State Busway Station								??
Bus Terminal	Bus	Terminal 43 - Whittier & Brannick Terminal								??
Bus Terminal	Bus	Terminal 46 - Red Line Bus Terminal								??
Bus Terminal	Bus	Terminal 49 - Mountain & Brand Terminal								??
Bus Transit Center	Bus	Terminal 26 -West LA Transit Ctr.					9	Moderate	3	No
Bus Transit Center	Bus	Terminal 27 -LAX Transit Ctr.					11	High	4	No
Bus Transit Center	Bus	Terminal 36 - Fox Hills Mall Transit Ctr.					7	Moderate	3	No

Asset Type	Service Line	Asset Name	Service Volume		Real Estate	Connectivity			Overall Criticality Score	Criticality
						Transit				
			Sum of Boardings and Alightings (Daily Weekday)	Qualitative Rating		Parking (# Spaces, not including street parking)	Connectivity Rating	Qualitative Rating		
Bus Transit Center	Bus	Terminal 50 - M.L. King Transit Ctr. (Compton)					10	High	4	No
Bus Transit Center	Bus	Terminal 52 - South Bay Galleria Transit Ctr.					14	High	4	No
Bus Yard	Bus	Division 1 Bus Yard								??
Bus Yard	Bus	Division 2 Bus Yard								??
Bus Yard	Bus	Division 3 Bus Yard								??
Bus Yard	Bus	Division 5 Bus Yard								??
Bus Yard	Bus	Division 6 Bus Yard								??
Bus Yard	Bus	Division 7 Bus Yard								??
Bus Yard	Bus	Division 8 Bus Yard								??
Bus Yard	Bus	Division 9 Bus Yard								??
Bus Yard	Bus	Division 10 Bus Yard								??
Bus Yard	Bus	Division 15 Bus Yard								??
Bus Yard	Bus	Division 18 Bus Yard								??
Customer Service (Building)	Location 85 - San Gabriel Valley Service Sector	Location 85 - San Gabriel Valley Service Sector								??
Customer Service (Building)	Terminal 24 - Ex Bus Yard	SAN FERNANDO CUST.SVC. CTR.14435 SHERMAN WAY #107								??
Maintenance Facility	Location 35 - Facilities Maintenance	REGIONAL REBUILD CENTER (CMF)								??
Human Resources (Building)	Location 29 -Cash Counting Room @ Div. 2									??
Lot	Terminal 25 - Toberman Lot	AIRSPACE LEASE UNDER SM FREEWAY-TOBERMAN LOT								??
Maintenance Facility	Location 30 -Metro Support Services Center	Metro's central maintenance facility for buses								High
Other	Location 14	South Park Shops								Not Metro-Owned
Parking	Terminal 219 - Parking Structure Adj. to B732									??
Station Building	Terminal 54 - Shatto Place	One of the station buildings at the Wilshire/Vermont red line station								??
Unknown	Location 33 -OCI	Near Union Station, colocated with Location 35 and Location 30								??
Unknown	Division 12 (Inactive)									Not Metro-Owned

Asset Type	Service Line	Asset Name	Service Volume		Real Estate	Connectivity			Overall Criticality Score	Criticality
						Transit				
			Sum of Boardings and Alightings (Daily Weekday)	Qualitative Rating		Parking (# Spaces, not including street parking)	Connectivity Rating	Qualitative Rating		
Unknown	Division 13									Yes - connected to Gateway Building
Unknown	Division 4 Non Revenue Vehicle									No
Unknown	Division 16									??

Table 17: Non-Passenger Facilities

	Address	Size (sq. ft.)	Priority
Rail Related			
Location 61 - Red Line Maintenance Of Way	284 S. Santa Fe Avenue, L.A. (Maintenance of Way Shops)		High
Location 66 - Blue Line Maintenance Of Way		81,270	High
Other			
Loc 24	14557 Sherman Way, Van Nuys (old Div. 8)		??
Loc 32	425 S. Main St., L.A. (SCRTD Headquarters Bldg., 4th & Main)	520	??
Location 34 - Vernon Yards	4462 Pacific Blvd., Vernon (Vernon Yards, LARy)	22,652	??
Loc 51	1900 S. Figueroa St., L.A. (Transit Police Headquarters)		??
Loc 55	316 W. 3rd St., L.A. (Miracle on Broadway Transit Police substation)		??
Loc 56	(Open)		??
Loc 57	(Open)		??
Loc 58	(Open)		??
Loc 59	(Open)		??
Location 80 - Materials Warehouse	628 Aliso St., LA, 90012	11,678	??
Location 81 - Surplus Office Space (6th Flr.)	818 W. 7th St., LA, 90017	9,747	??
Location 82 - Office Space (6 flrs. 23,24,27,28,29 & 37)	707 Wilshire Blvd., LA, 90017	43,822	??
Location 83 - Office/Warehouse Bldg.	3730 Monterey Rd., El Monte, 91731	49,005	??
Location 84 - San Fernando Valley Service Sector	9760 Topanga Canyon Bl., Chatsworth, 91311	365,469	??
Location 86 - South Bay Service Sector	680 Knox St., Suite 150, Torrance,	171,191	??
Location 87 - Gateway Cities Service Sector	7878 Telegraph Rd., Downey, 90240	10,000	??
Loc 99 USG	Union Station - Gateway, includes the MTA building, the east portal to Union Station, and Patsouras Plaza	186,680	High

Table 18: Connectivity Information

Stop Name	Main Rail Line	Connecting Lines: Red (Rail)	Purple (Rail)	Blue (Rail)	Green (Rail)	Gold (Rail)	Expo (Planned Rail)	Silver (Bus)	Orange (Bus)	Rapid Bus	Number of Rapid Bus Lines	Express Bus	Number of Express Bus Lines	Local Bus	Number of Local Bus Lines	El Monte Busway	Foothill Transit Silver Streak	LAX Flyaway	Amtrak	Santa Monica Muncipial Bus Lines	City of Santa Clarita Transit	Metroliner 902	LADOT DASH	LA DOT Commuter Express	Torrance Transit	Santa Monica Transit	Montebello Transit	Orange County Transportation Authority	Antelope Valley Transit Authority	MetroLink	Connectivity Rating
103rd Street Station	Blue			1																											1
1st Street Station	Blue			1																											1
5th Street Station	Blue			1																											1
Anaheim Station	Blue			1																											1
Artesia Station	Blue			1						760, 762	2																				3
Compton Station	Blue			1																											1
Del Amo Station	Blue			1																											1
Firestone Station	Blue			1						715	1			115	1																3
Florence Station	Blue			1						711	1																				2
Grand Station	Blue, Silver			1				1		770	1			14, 35, 37, 38, 55, 335, 603	7								1		1						12
Long Beach Transit Mall	Blue			1																											1
Pacific Station	Blue			1																											1
PCH Station	Blue			1																											1
Pico Station	Blue, Silver, Expo			1			1	1		728, 730	2	442, 445, 460	3	30, 81	2																10
San Pedro Station	Blue			1																											1
Slauson Station	Blue			1																											1
Vernon Station	Blue			1						705	1																				2
Wardlow Station	Blue			1																											1
Washington Station	Blue			1																											1
Willow Station	Blue			1																											1
Imperial / Wilmington (Rosa Parks) Station	Blue, Green			1	1					753	1			55, 120, 121, 205, 355, 612	6								1								10
7th Street / Metro Center Station	Blue, Purple, Red, Silver, Expo	1	1	1			1	1		720, 760, 770	3	439,445, 450x, 485, 487, 489, 720, 760, 770	9	14, 16, 18, 20, 26, 37, 51, 52, 53, 55, 60, 62, 66, 70, 71, 76, 78, 79, 81, 96, 316, 352, 355, 378	24		1				1		1	1	1	1	1	1	1		50
Allen Station	Gold					1																									1
Atlantic Station	Gold					1				762	1																				2
Chinatown Station	Gold					1																									1
Del Mar Station	Gold					1				762	1																				2
East LA Civic Center Station	Gold					1																									1
Fillmore Station	Gold					1																									1
Heritage Square / Arroyo Station	Gold					1																									1
Highland Park Station	Gold					1																									1
Indiana Station	Gold					1																									1
Lake Station	Gold					1																									1
Lincoln Heights / Cypress Park Station	Gold					1				751	1																				2
Little Tokyo / Arts District Station	Gold					1				730	1																				2
Maravilla Station	Gold					1																									1

Stop Name	Main Rail Line	Connecting Lines: Red (Rail)	Purple (Rail)	Blue (Rail)	Green (Rail)	Gold (Rail)	Expo (Planned Rail)	Silver (Bus)	Orange (Bus)	Rapid Bus	Number of Rapid Bus Lines	Express Bus	Number of Express Bus Lines	Local Bus	Number of Local Bus Lines	El Monte Busway	Foothill Transit Silver Streak	LAX Flyaway	Amtrak	Santa Monica Muncipial Bus Lines	City of Santa Clarita Transit	Metroliner 902	LADOT DASH	LA DOT Commuter Express	Torrance Transit	Santa Monica Transit	Montebello Transit	Orange County Transportation Authority	Antelope Valley Transit Authority	MetroLink	Connectivity Rating
Mariachi Plaza / Boyle Heights Station	Gold					1																									1
Memorial Park Station	Gold					1				780	1																				2
Mission Station	Gold					1																									1
Pico / Aliso Station	Gold					1																									1
Sierra Madre Villa Station	Gold					1																									1
Soto Station	Gold					1				751	1																				2
Southwest Museum Station	Gold					1																									1
Avalon Station	Green				1									48, 51, 52, 53, 352	5																6
Aviation Station (LAX Shuttle Connection)	Green				1									120, 625, 626	3					1											5
Crenshaw Station	Green				1					710, 757	2			126, 210	2																5
Douglas Station	Green				1									125	1																2
El Segundo Station	Green				1																										1
Harbor Freeway Station	Green, Silver				1			1		745	1	445, 450X, 550	3	45, 81, 120, 246, 247	5									1				1			13
Hawthorne Station	Green				1					740	1	442	1	40, 126, 212, 312	4																7
Lakewood Station	Green				1									117, 265, 266	3																4
Long Beach Station	Green				1					760	1			60, 251	2																4
Mariposa Station	Green				1																										1
Norwalk Station	Green				1							460, 577X	2	111, 115, 121, 125, 270, 311	6																9
Redondo Beach Station	Green				1									126, 215	2																3
Vermont Station	Green				1					754	1			204, 206, 209	3																5
Balboa Station	Orange								1					164, 236, 237	3									1							5
Canoga Station	Orange								1					164, 165	2						1										4
De Soto Station	Orange								1					164, 244	2						1										4
Laurel Canyon Station	Orange								1					156, 230, 656	3																4
North Hollywood Station	Orange								1																						1
Pierce College	Orange								1					164, 243	2																3
Reseda Station	Orange								1	741	1			240	1																3
Sepulveda Station	Orange								1	734	1			234	1																3
Tampa Station	Orange								1					242	1																2
Vallley College Station	Orange								1					156, 167, 656	3							1	1	1							7

Stop Name	Main Rail Line	Connecting Lines																													Connectivity Rating
		Red (Rail)	Purple (Rail)	Blue (Rail)	Green (Rail)	Gold (Rail)	Expo (Planned Rail)	Silver (Bus)	Orange (Bus)	Rapid Bus	Number of Rapid Bus Lines	Express Bus	Number of Express Bus Lines	Local Bus	Number of Local Bus Lines	El Monte Busway	Foothill Transit Silver Streak	LAX Flyaway	Amtrak	Santa Monica Muncipial Bus Lines	City of Santa Clarita Transit	Metroliner 902	LADOT DASH	LA DOT Commuter Express	Torrance Transit	Santa Monica Transit	Montebello Transit	Orange County Transportation Authority	Antelope Valley Transit Authority	MetroLink	
Van Nuys Station	Orange								1	761	1			154, 156, 233, 237, 656	5						1	1	1								10
Warner Center Station	Orange								1	750	1			150, 161, 164, 245, 645	5						1										8
Woodley Station	Orange								1					164, 237	2																3
Woodman Station	Orange								1					154, 158	2																3
Wilshire/ Western	Purple		1							710, 720, 757	3																				4
Wilshire / Normandie Station	Purple		1							720	1																				2
Civic Center Station	Purple, Red, Silver	1	1					1		714, 728, 730, 733, 740, 745, 770, 794	8	439, 445, 485, 487, 489	5	2, 4, 10, 14, 30, 31, 33, 37, 40, 42, 45, 48, 68, 70, 71, 76, 78, 79, 81, 83, 84, 90, 91, 92, 94, 96, 302, 333, 378	27		1				1		1	1	1		1		1		50
Pershing Square Station	Purple, Red	1	1					1		720, 728, 730, 733, 740, 745, 770, 794,	8	445, 460, 485, 487, 489	5	2, 4, 10, 14, 16, 18, 28, 30, 33, 37, 40, 42, 45, 48, 53, 55, 62, 70, 71, 76, 78, 79, 81, 83, 90, 91, 92, 94, 96, 302, 316, 355, 378,	33		1														50
Westlake / McArthur Park Station	Purple, Red	1	1							720	1	487, 489	2	18, 20, 26, 51, 52, 200, 352, 603	8		1						1								15
Wilshire / Vermont Station	Purple, Red	1	1							720, 754	2											1									5
Union Station	Purple, Red, Gold, Silver	1	1			1		1		704, 728, 733, 740, 745, 770	6	439, 442, 445, 485, 487, 489	6	40, 42, 68, 70, 71, 76, 78, 79, 378,	9	1	1	1	1		1		1	1	1			1	1	1	36
Hollywood / Highland Station	Red	1								780	1																				2
Hollywood / Vine Station	Red	1								780	1																				2

Stop Name	Main Rail Line	Connecting Lines																													Connectivity Rating
		Red (Rail)	Purple (Rail)	Blue (Rail)	Green (Rail)	Gold (Rail)	Expo (Planned Rail)	Silver (Bus)	Orange (Bus)	Rapid Bus	Number of Rapid Bus Lines	Express Bus	Number of Express Bus Lines	Local Bus	Number of Local Bus Lines	El Monte Busway	Foothill Transit Silver Streak	LAX Flyaway	Amtrak	Santa Monica Muncipal Bus Lines	City of Santa Clarita Transit	Metroliner 902	LADOT DASH	LA DOT Commuter Express	Torrance Transit	Santa Monica Transit	Montebello Transit	Orange County Transportation Authority	Antelope Valley Transit Authority	MetroLink	
Hollywood / Western Station	Red	1								757, 780	2																				3
Universal City Station	Red	1								750	1																				2
Vermont / Beverly Station	Red	1								714, 754	2																				3
Vermont / Santa Monica Station	Red	1								704, 754	2																				3
Vermont / Sunset Station	Red	1								754	1																				2
North Hollywood Station	Red, Orange	1							1					152, 154, 156, 183, 224, 353, 363, 656	8						1	1									12
El Monte Bus Station	Silver							1		770	1	486, 488, 492, 494, 481, 577X	6	190, 194, 76, 270, 176, 178, 269, 282	8		1														17
California State University, Los Angeles	Silver							1				485, 487, 489	3	71, 256, 665	3		1													1	9
Los Angeles County-USC Medical Center	Silver							1		751	1	485, 487, 489	3	70, 71, 251, 605	4		1														10
Spring St. & 1st St.	Silver							1		728, 733, 770	3						1														5
Grand St. & 3rd St. (Southbound) Olive St. & Kosciuszko Way (Northbound)	Silver							1		770	1																				2
Flower St. & 5th St. (Southbound) Olive St. & 5th St. (Pershing Square) (Northbound)	Silver	1	1					1		720, 728, 730, 740, 745, 770, 794	7						1														11
Flower St. & Olympic Blvd. (Southbound) Figueroa St. & Olympic Blvd. (Northbound)	Silver							1		728	1	439, 442, 445, 460	4	28, 81	2																8
Flower St. & Adams Blvd. (Southbound) Adams Blvd. & Figueroa St. (Northbound)	Silver							1				442, 445, 460	3	37, 81	2																6
37th Street	Silver							1				445, 460, 442, 550	4	81, 102, 200	3									1				1			10
Slauson Station	Silver							1		745	1	442, 445, 460, 550	4	45, 81, 108, 358	4									1	1			1			13
Manchester Station	Silver							1		745		445, 460, 550	3	45, 81, 115, 305	4									1	1			1			11
Rosecrans	Silver							1				445, 550	2	246, 247, 125	3																6
Artesia Transit Center	Silver							1				445, 450X, 550	3	52, 130, 205, 352	4										1						9

Data Sources

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- *Adopted Budget, FY 2011* (http://www.metro.net/about_us/finance/images/FY11BudgetBook.pdf)
- *Comprehensive Annual Financial Report* (for the fiscal year ending June 30, 2009) (http://www.metro.net/about_us/finance/images/cafr_2009.pdf)

Measure R Information:

- *2009 Long Range Transportation Plan* (http://www.metro.net/projects_studies/images/final-2009-LRTP.pdf)
- Online Measure R updates (http://www.metro.net/measurer)

Joint Development Information:

- Joint Development Program Factsheet (http://www.metro.net/projects_studies/joint_development/images/joint_dev_project_fact_sheet.pdf)

Ridership Statistics:

- Spreadsheets provided by Theresa Arslanian and Alvin Kusumoto, Metro
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